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Volume 4 APRIL, 1934 Number 1

Journal of Sedimentary Petrology

A Publication of the Society of Economic Paleontologists and Mineralogists
a Division of
The American Association of Petroleum Geologists

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Journal of Sedimentary Petrology

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The Journal of Sedimentary Petrology is published by the Society of Economic Paleontologists and Mineralogists, a division of The American Association of Petroleum Geologists. Numbers are issued in April, August and December.

The subscription price of the Journal of Sedimentary Petrology is $3.00 per year prepaid to addresses in the United States, Mexico, Cuba, Porto Rico, Panama Canal Zone, Republic of Panama, Dominican Republic, El Salvador, Bolivia, Colombia, Honduras, Nicaragua, Peru, Hawaiian Islands, Philippine Islands, Guam, Samoan Islands.

Single numbers, $1.50 each.

Postage is charged extra: For Canada, 20 cents on annual subscriptions (total $3.20), and for all other countries in the Postal Union, 40 cents on annual subscriptions (total $3.40).

Claims for non-receipt of preceding numbers of the Journal must be sent to the secretary-treasurer within three months of the date of publication in order to be filled gratis.

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GEORGE BANTA PUBLISHING COMPANY, MENASHA, WISCONSIN, U.S.A.

Journal
of
Sedimentary Petrology

VOLUME 4
APRIL, 1934-DECEMBER, 1934
NOS. 1-3

W. H. TWENHOFEL, EDITOR

PUBLISHED AT MENASHA, WISCONSIN
BY THE
SOCIETY OF ECONOMIC PALEONTOLOGISTS AND
MINERALOGISTS
A SECTION OF
THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

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Articles submitted for publication to the JOURNAL OF SEDIMENTARY PETROLOGY should have a prefatory abstract and sufficient postage should be sent by the author to prepay the return of the manuscript as it has been found that many articles require more or less revision before publication.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 4, NO. 1, PP. 3–11, TABLES 1–6,
APRIL, 1934

A STUDY OF SEDIMENTS FROM THE NORTH CAROLINA AND FLORIDA COASTS

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ABSTRACT

A study of the shallow water coastal deposits in the North Carolina and Florida regions shows a persistent suite of heavy minerals consisting of ilmenite, staurolite, epidote, zircon, garnet, sillimanite, cyanite, hornblende, leucoxene, tourmaline, rutile, hypersthene, apatite, magnetite, monazite?, and andalusite. Epidote is the dominant nonopaque mineral in the Florida region, while staurolite is the most abundant nonopaque mineral in the North Carolina region. The percentages of mineral constituents show considerable local variation. The heavy minerals make up less than 2 per cent of the samples and the shell matter ranges from 2.94 to 93.53 per cent. The light minerals consist essentially of quartz with a small amount of feldspar and glauconite. There are also more or less ash and glass.

This study was undertaken for the purpose of making available data concerning the sediments of the present shallow water coastal deposits. The samples examined are from two localities; namely the North Carolina area, which includes the region from Cape Lookout to Cape Fear, and the Florida area, which includes the region from St. Johns River to Cape Canaveral with the exception of sample No. 57 which is located off shore from the mouth of the St. Lucie River.

The writer wishes to express his appreciation for the helpful direction of the research by Dr. W. H. Twenhofel and to the commanding officer of the U. S. Coast and Geodetic Survey Ship Lydonia for collecting the samples. The work was done in the sedimentation Laboratory of the University of Wisconsin.

The locations of the samples and the depth of water from which derived, together with the surface current velocity and direction, and the temperature of the water, where obtainable, are given for the North Carolina area in Table 1 and for the Florida area in Table 2.

PROCEDURE AND RESULTS

Samples 76 to 94 inclusive and sample 99 are muds, while the remainder of the samples are sands.

The percentage of clay in the muds was determined by agitating for 24 hours using sodium hydroxide as a deflocculating agent. The sand and clay were then separated by the fractional decantation method. The fine material which did not settle within thirty seconds was considered clay and decanted. The sands and silts were treated with tetrabromoethane (Sp. Gr. 2.9–3.0), using the method as described by Reed,[1] and separated into light and heavy minerals. Both portions were then dried

TABLE 1. *Location and Depth of Samples from the North Carolina Region*

Sample No.	Latitude North	Longitude West	Depth in Feet	Surface Current Velocity in Knots	Surface Current Direction T.	Temperature Centigrade
1	34°36.3′	77°06.4′	46			26.2°
2	34°21.3′	77°33.4′	50	.6	43°	23.7°
4	34°29.8′	77°19.4′	31	.15	0°	24.7°
5	34°08.6′	77°31.5′	64	.4	65°	24.5°
6	34°36.8′	77°02.4′	49	.15	257°	24.0′
10	34°23.0′	76°58.2′	81	.03	44°	15.5°
11	34°26.3′	77°38.0′	60.5			
12	34°14.9′	77°28.2′	66			
13	34°14.0′	77°36.0′	50			
14	34°36.3′	77°09.3′	44			
15	34°15.7′	77°29.7′	74	.4	275°	23.8°
16	34°24.0′	77°01.5′	74			
17	34°37.2′	77°07.0′	42	.0		25.8°
18	34°46.7′	76°47.3′	72			
19	34°21.5′	77°37.6′	35			
20	34°27.0′	77°17.1′	52	.04	233°	22.4°
21	34°14.3′	77°37.9′	51	.55	30°	24.3′
22	34°21.6′	77°07.0′	75			
23	34°39.3′	76°57.8′	44			
24	34°39.3′	76°57.8′	42	.25	0°	23.3°
25	33°21.7′	77°14.5′	66	.6	270°	26.1°
26	34°21.2′	77°24.6′	53			
27	34°39.2′	77°57.8′	36	.5	295°	28.8°
28	34°25.2′	76°58.1′	75			
29	34°16.0′	77°38.0′	48			20.5°
30	34°34.0′	76°57.0′	61	.3	345°	23.3°
31	34°36.7′	76°34.9′	52			22.5°
32	34°28.0′	77°14.0′	50			
33	34°35.6′	77°08.8′	51	1.08		27.0°
34	34°39.0′	76°52.0′	48	.0		26.1°
35	34°36.8′	76°44.7′	52			
37	34°13.5′	77°30.0′	65			
38	34°21.2′	77°34.6′	50			
39	34°18.3′	77°41.3′	26			
41	34°16.2′	77°27.2′	66			
42	34°32.3′	77°18.0′	28	.0		22.8°
43	34°26.9′	76°43.7′	81			
44	34°18.0′	77°25.9′	54			
46	34°17.4′	77°35.0′	50			
47	34°17.1′	77°35.8′	51			
48	34°39.0′	76°56.0′	48	.3	300°	16.6°
50	34°36.0′	77°34.8′	47	.3	317°	22.5°
52	34°36.2′	77°09.6′	44	.47	53°	27.3°
53	34°04.5′	77°39.0′	60			
59	33°20.9′	77°36.3′	72	.6	90°	27.0°
60	33°59.8′	77°36.8′	72			25.5°
62	33°32.2′	77°46.4′	66	.3	56°	24.2°
67	33°59.0′	77°54.0′	28			20.8°
70	34°07.5′	77°36.1′	65			
71	34°13.0′	77°13.0′	82	.2	80°	26.8°
72	34°22.6′	76°55.6′	81	.45	40°	
73	34°15.0′	77°28.0′	70			
74	34°17.3′	77°33.3′	60	.77	37°	20.5°
75	34°19.0′	77°11.0′	72	.0		
78	34°41.0′	76°49.6′	33	.5	305°	22.8°
82	33°51.2′	77°56.7′	26	.1	320°	25.5°
89	34°36.5′	77°02.3′	50	.0		23.5°
91	34°37.5′	77°32.5′	28	.0		22.0°
94	34°37.4′	77°08.2′	30			26.5°
95	34°17.2′	77°32.7′	54	.35	30°	23.8°

TABLE 1 (*Continued*)

Sample No.	Latitude North	Longitude West	Depth in Feet	Surface Current Velocity in Knots	Surface Current Direction T.	Temperature Centigrade
96	34°36.6′	77°06.4′	48	.2	54°	
97	34°00.7′	77°40.1′	57	.2	349°	24.2°
99	34°34.8′	77°12.2′	35	.04	327°	26.7°
100	34°36.0′	77°05.0′	48			27.0°
101	34°28.3′	77°24.0′				
102	34°17.4′	77°37.2′	47			
103	34°11.2′	77°33.4′	59			
104	34°27.0′	76°17.0′	46			
105	34°28.2′	77°11.9′	51			22.0°
106	34°06.0′	77°37.6′	58			24.6°
107	33°12.0′	77°15.0′	76	.4	0°	26.1°
108	34°37.2′	77°57.8′	45	.3	260°	25.0°
109	34°27.4′	77°17.3′	42	.25	17°	22.3°
110	34°27.2′	77°17.6′	54			22.6°
111	34°30.2′	77°20.1′	30	.12	36°	22.4°

TABLE 2. *Location and Depth of Samples from the Florida Region*

Sample No.	Latitude North	Longitude West	Depth in Feet	Surface Current Velocity Knots	Surface Current Direction T.	Temperature Centigrade
3	29°25.0′	81°00.0′	59			15.5°
7	29°24.2′	80°48.8′	71			18.2°
8	28°59.4′	80°41.2′	62			17.0°
9	29°20.0′	80°58.3′	10.4			16.5°
36	29°18.3′	81°02.1′	39			13.3°
40	29°03.5′	80°53.5′	30			
45	28°56.4′	80°44.0′	36			18.3°
49	29°15.3′	80°58.2′				
51	29°18.2′	81°00.3′	54			18.3′
54	30°23.6′	81°26.0′	27			11.6°
55	29°26.0′	80°44.0′	69			18.5°
56	29°34.0′	80°27.4′				
57	27°18.3′	81°01.9′	36		45°	
58	29°10.1′	80°47.2′	11			
61	29°18.7′	81°02.4′	43			
63	28°51.6′	80°45.8′	39			17.2°
64	29°15.1′	79°58.8′	57	1.7	135°	19.7°
65	29°04.8′	80°54.2′	39			13.3°
66	29°09.4′	80°46.2′	56			13.9°
68	29°28.2′	80°40.0′	24			19.3°
69	29°17.2′	81°57.2′	66			
76	30°22.2′	81°20.6′	56			
77	29°18.2′	81°02.0′	59			
79	29°17.4′	81°01.8′	46	1.4		17.2°
80	29°07.5′	80°55.2′	61			15.0°
81	29°17.9′	80°59.7′	57	.8	0°	12.7°
83	30°22.8′	80°20.5′	64			13.0°
84	30°23.6′	81°29.4′	28			11.1°
85	29°04.2′	80°53.1′	59			17.7°
86	29°05.7′	80°52.1′	70			18.8°
87	29°00.8′	80°49.3′	66			17.2°
88	29°11.9′	80°57.9′	57			15.5°
90	29°24.1′	81°02.1′	61			18.0°
92	29°30.0′	81°05.0′	63			16.0°
93	29°00.4′	80°46.9′	72			12.0°
98	28°57.7′	80°45.4′	56			15.5°

and weighed and the percentage of heavy minerals determined.

Table 3 gives the percentage of heavy minerals in all the samples and the percentage of clay in the muds. The percentage of heavy minerals ranges from 0.04 to 1.99 per cent and averages 0.68 per cent.

Light Minerals.—The light minerals were mounted in oils for microscopic examination. They were found to consist essentially of quartz with a small amount of feldspar and glauconite. Ash and glass, the origin of which are unknown, occurs in varying amounts. The quartz ranges from angular to well-rounded with the larger grains showing frosting and pitting.

Heavy Minerals.—The heavy minerals were mounted in Canada balsam and identified by optical methods.

[1] Reed, R. D., Some methods for heavy mineral investigation: *Econ. Geology*, vol. 19, pp. 326–327, 1924.

TABLE 3. *Percentage of Heavy Minerals and of Clay*

Sample No.	Per Cent Heavy Minerals	Sample No.	Per Cent Heavy Minerals	Sample No.	Per Cent Heavy Minerals	Per Cent Clay
1	.66	38	.77	75	.23	
2	.60	39	1.13	76	.34	24.87
3	.32	40	1.49	77	.71	8.09
4	.68	41	1.21	78	1.14	6.24
5	.35	42	.99	79	.77	26.10
6	.49	43	.99	80	.54	23.59
7	.31	44	.82	81	.98	7.32
8	.58	45	.20	82	.42	10.47
9	.42	46	.94	83	.15	20.10
10	.47	47	.48	84	.08	59.11
11	.59	48	.20	85	.36	20.90
12	1.18	49	.08	86	.31	48.69
13	1.70	50	.98	87	.40	41.48
14	.38	51	.12	88	.54	19.29
15	.84	52	.06	89	.62	14.98
16	.75	53	.20	90	.51	28.23
17	1.99	54	.31	91	.74	23.19
18	.72	55	.44	92	.60	28.01
19	1.88	56	.13	93	.54	11.96
20	.32	57	.80	94	1.11	6.59
21	1.14	58	.07	95	.96	
22	1.04	59	.58	96	.83	
23	1.12	60	.64	97	.73	
24	.62	61	.58	98	.07	
25	.86	62	.39	99	.22	5.65
26	.44	63	1.28	100	.82	
27	1.81	64	.50	101	1.10	
28	.74	65	.30	102	.88	
29	1.68	66	.04	103	.70	
30	1.33	67	1.42	104	.62	
31	1.29	68	.06	105	.71	
32	.78	69	.32	106	.40	
33	.78	70	.81	107	1.17	
34	.64	71	.34	108	.72	
35	.80	72	.23	109	.34	
36	1.70	73	.18	110	.72	
37	.56	74	.13	111	.97	

Table 4 gives the percentage of the different heavy minerals present in the samples from the North Carolina area, while Table 5 gives the same for the Florida area. The percentage figures were obtained by counting about 600 grains in each slide. While the percentage figures do not have a high degree of accuracy, they do give the relative abundance of the different minerals present.

DESCRIPTION OF MINERALS

Andalusite.—Andalusite occurs as subangular to well-rounded grains, which are pleochroic from pink to colorless. Black inclusions are fairly common. The average diameter of the grains is about 0.2 mm.

Apatite.—The grains are fresh, well-rounded and colorless. Black and colorless inclusions are common. The diameters of the grains range from 0.1 mm. to 0.3 mm.

Cyanite.—Cyanite is commonly present as rectangular shaped unworn grains, although some oval grains are present. The 100 and 010 cleavages are well developed. Some grains show alteration to a yellowish-brown mineral along cleavage cracks. Small black inclusions are quite common. The size of the grains range from 0.2 mm. by 0.4 mm. to 0.05 mm. by 0.1 mm.

Epidote.—The grains range from angular to well-rounded, with the subangular to well-rounded grains predominating. The color is pistachio green, while the pleochroism is from yellowish-green to colorless. Interference figures of the "compass needle" type are quite common. Pink, black and colorless inclusions are fairly abundant. The grains range in size from 0.05 mm. to 0.4 mm.

Garnet.—Garnet occurs as colorless, pink and rarely green grains. The grains range in shape from angular to well-rounded with the angular and subangular grains predominating. Pitted and etched surfaces are quite common. Black, pink, brown and colorless inclusions are not rare. The grains range in size from 0.05 mm. to 0.5 mm.

Hornblende.—The color ranges from dark-green to light-green with many grains pleochroic from dark-green to yellowish-green. Most grains are lath-shaped with frayed ends, or are angular, but some grains have a roughly elliptical shape. Small brown, black and colorless inclusions are rare. The average size of the lath-shaped grains is 0.1 mm. by 0.3 mm.

Hypersthene.—Hypersthene occurs as ragged prismatic grains with distinct cleavage parallel to 110. The color is grayish-green, while the pleochroism is very marked from green to red. Some grains are altered along cleavage cracks to a brown mineral. Black, brown and colorless inclusions are quite common. The grains range in size from 0.1 mm to 0.3 mm.

Ilmenite.—Ilmenite occurs as subangular to rounded grains with a submetallic luster in reflected light. Partial alteration to leucoxene is not uncommon.

Leucoxene.—This mineral occurs as rounded grains, which are opaque in transmitted light, white or yellowish-white in reflected light, and has a pitted unglazed porcelain appearance. The grains range in size from 0.1 mm. to 0.5 mm.

Magnetite.—This mineral is present as angular, well-rounded grains as well as octahedral crystals.

Monazite.—Probably present in small amounts and classified as epidote. In unsized samples mounted in Canada balsam it is almost impossible to positively identify this mineral.

Sillimanite.—This mineral occurs as colorless rectangular shaped grains with rounded to ragged ends. Some grains show a slight alteration to a brownish mineral. Pink, brown and colorless inclusions arranged parallel to the direction of elongation are common. The grains range in size from 0.1 mm. to 0.5 mm.

TABLE 4.—*Analyses of the Heavy Minerals from the North Carolina Area*

Sample No.	Staurlote	Epidote	Zircon	Garnet			Sillimanite	Cyanite	Hornblende	Tourmaline				Rutile		Hypersthene	Apatite	Andalusite	Opaque Minerals	Nonopaque Minerals
				Colorless	Pink	Green				Brown	Green	Mauve	Blue	Fox-red	Green-brown					
1	29	8	14	7	4		12	7	11	5				1		1	1		53	47
2	32	10	24	8	8		5	3	3	4				2			1		49	51
4	53	7	8	4	7		7	3	5	3				1		1		1	56	44
5	44	10	13	5	7		7	3	3	5				1		1	1	x	49	51
6	35	10	4	4	2		11	6	20	5				1		1	1		38	62
10	37	10	10	1	8		13	2	10	5		2	x	1		1			43	57
11	43	12	10	6	4		11	5	6	3								x	52	48
12	53	4	6	4	6		11	6	6	2				1		1			46	54
13	54	6	6	3	6		11	4	3	5				1		1		x	48	52
14	34	7	18	4	4		16	3	8	4			x	1		1			56	44
15	32	10	11	12	3		14	6	6	3			x	2		1			48	52
16	35	3	26	3	8		10	2	6	5				1		x	1		49	51
17	34	8	16	9	5		6	3	11	5				2		x	1		48	52
18	28	9	11	9	7		10	3	17	5				1		x		x	47	53
19	44	6	17	10	3		9	2	4	3			x	1		x	1		66	34
20	44	8	14	6	7		6	3	9	2				1		x	x		40	60
21	42	6	11	7	6		10	3	9	5			x	1		x	x		56	44
22	50	7	13	5	12		6	1	3	3									41	59
23	38	7	24	4	9		8	2	4	3				1					53	47
24	21	11	11	15	10		12	2	15	1				1		1	x	x	44	56
25	35	7	22	8	5		9	4	6	1				1		1	1		52	48
26	43	5	17	5	6		9	1	7	6			x	1		x	x		49	51
27	49	5	18	6	2		7	2	5	3			1	1			1		56	44
28	22	15	27	11	7		4	3	8	2				1		x			46	54
29	45	11	9	3	5		9	4	7	3				2		1	1		46	54
30	33	11	13	6	11		9	3	8	3				2		x	1		46	54
31	7	10	9	11	5		8	2	44	2				1		x	1		42	58
32	41	10	19	6	6	x	5	3	4	4				1		1			60	40
33	2	11	9	12	6		8	5	46	1						x	x		39	61
34	9	17	7	13	7		10	3	30	3				1		x	x		40	60
35	63	7	3	2	8		7	3	2	3				1		1			25	75
37	63	6	3	1	9		9	3		6							x	x	45	55
38	59	8	5	5	7		5	3	1	7						x			39	61
39	19	11	40	9	7	x	6	2	3	2				1		x	x		60	40
41	44	5	27	4	8		5	2	2	2				1			x		49	51
42	38	14	13	3	10		9	4	4	3				1			1	x	43	57
43	13	12	7	7	7	x	9	2	36	3				2		2	x	x	34	66
44	41	11	11	11	6		9	4	2	3				1			1		60	40
46	50	8	9	1	9		9	5	5	3				1		x			35	65
47	50	4	20	4	11		4	2	1	3				1					66	34
48	13	19	6	3	13		7	4	33	1				1		x	x		45	55
50	10	13	11	4	12		10	2	32	1			x	2		2	1		40	60
52	36	11	16	3	13		11	2	4	2				2		x	x		34	66
53	62	5	3	3	10		3	4	1	2	3	1		2		1			40	60
59	26	4	46	10	5	x	3	4		1				1					35	65
60	42	5	29	4	10		3	4		2				1					49	51
62	14	35	22	3	4		13		5	2				2					42	58
67	51	11	8	2	12		4	4	5	2				1				x	34	66
70	35	11	18	2	6		6	7	7	4		1		3		x	x		46	54
71	49	10	13	3	6		7	6	2	2				1		1			46	54
72	32	13	17	10	12		4	5	4	1				1		1		x	53	47
73	37	13	18	8	5		7	7	3	1				1					70	30
74	66	4	8	2	5		7	3	1	3	1		x						68	32
75	47	4	24	2	12		4	4	1					2			x		75	25
78	5	23	14	3	11		7	1	32	1	1			1		x	1		55	45
82	22	20	24	7	6		3	4	7	2				3		2			61	39
89	27	16	23	4	8		3	4	10	1				3		1			56	44
91	3	32	9	6	3		5	x	40	x				1		x	1		40	60
94	6	37	19	5	3		4	2	20	2				1	1	x	x		53	47
95	32	7	37	3	15		1	1	1	2				1					54	46
96	20	11	37	6	4		4	4	7	3		1		2		1			56	44
97	37	9	20	7	12	x	2	4	3	2			x	3			1		55	45
99	12	23	36	6	6		1	2	10	1				1			1	1	64	36
100	35	20	11	7	10		3	2	6	4			x	1			1		58	42
101	32	6	25	8	10		7	4	4	2				1			1		54	46
102	40	3	38	2	8		2	2	2	2			x	1					51	49
103	44	13	15	3	8		4	6	1	2				2			1	1	65	35
104	44	8	18	6	5		6	2	5	2			x	2		1	1	1	63	37
105	46	4	16		18		4	3	7	2				x					48	52
106	41	4	22	8	11		5	4	2	2	1								51	49
107	42	14	31	4	4		5												50	50
108	17	10	26	8	17		1	6	11	1				2		1			66	34
109	42	9	20	20			4		4	1									64	36
110	54	4	12	3	13		4	5	2	2									42	58
111	35	5	33	4	10	x	5	3	2	1						1	1	x	57	43

x *less than 1 per cent.*

TABLE 5.—*Analyses of the Heavy Minerals from the Florida Area*

Sample No.	Staurolite	Epidote	Zircon	Garnet			Sillimanite	Cyanite	Hornblende	Tourmaline				Rutile		Hypersthene	Apatite	Andalusite	Opaque Minerals	Nonopaque Minerals
				Colorless	Pink	Green				Brown	Green	Mauve	Blue	Fox-red	Green-brown					
3	11	40	8	3	2	x	14	1	13	3				3		1		1	41	59
7	16	35	26	7			6	1	6	1				2					60	40
8	14	42	17	2	3		11	1	4	4				2					36	64
9	11	38	13	4	1		16	1	10	3				2		1			50	50
36	5	35	9	1	2		15	4	25	2				1		1			20	80
40	4	41	6		1		9	3	31	2			x	2		1			33	67
45	1	42	4	1			16	2	31	1			x	2					40	60
49	11	49	6	1	3		15	2	10	2				1					31	69
51	12	43	10	4	4	x	13	1	4	1		1		5		1	1		28	72
54	14	42	17	1	2		12	5	2	1	1	1		2					41	59
55	19	42	13	3	7		6	4	2	2				2					50	50
56	20	36	10		14		10	3	5	2									50	50
57	6	52	16	3	1		9	3	5	2				3					41	59
58	28	34	13	6	4		7	2	4		1		x	1					50	50
61	4	44	14	3			11	6	15	2				1					39	61
63	6	44	19	2	2	x	7	4	7	1		1	x	3	4				44	56
64	20	38	15	6			10	1	5	2				3					45	55
65	6	38	13	2	2		10	5	13	1				6	4				63	37
66	23	40	14		9		9	3	1					1					50	50
68	32	36	9	1	8		9	1	2	1				1					59	41
69	16	38	16	2	3	x	9	2	6	2		1		5					44	56
76	1	50	14	1	1		5	2	19	2				4			1		30	70
77	9	41	20	2	5	x	7	1	7	2	2		x	4					40	60
79	7	38	21	2	2		10	1	9	3				5			2		41	59
80	5	47	18	1	3		7	3	11	1	1			2			1		45	55
81	13	37	27	4	2		7	2	3	2	1			1		1			46	54
83	3	60	12		2		6	2	8	1				4	1	1			51	49
84	6	50	23	1	2		9	2	3	1				3					56	44
85	6	50	23	1	1		6	3	5	1	1			3					50	50
86	3	52	14	2	2		6	4	8	2				3	4				43	57
87	6	47	24	1			8	3	6	1				4					54	46
88	3	48	23	5			5	1	12	1				2					35	65
90	5	41	36	3	2	x	2	2	5	1				2	1				57	43
92	5	41	27	1			9	2	13	x				2					52	48
93	4	58	11	1			5	3	11	1				3	2		1		47	53
98	10	61	13	2	2		3	1	4	1				3					41	59

x less than 1 per cent.

Staurolite.—Most of the grains of this mineral are subangular to angular and have a marked hackly fracture. The color ranges from a straw-yellow to a brownish-yellow. The pleochroism is moderate from brownish-yellow to light-yellow or colorless. Colorless, brown, pink and black inclusions are quite abundant. Some grains are quite free from inclusions, while other grains are filled with inclusions. The grains range in size from 0.1 mm. to 0.5 mm.

Rutile.—Rutile occurs as well formed prismatic crystals, and rarely as well-rounded grains. The color ranges from reddish-brown to a greenish-brown. The size of grain ranges from 0.05 mm. to 0.2 mm.

Tourmaline.—This mineral occurs both as prismatic and well-rounded grains. The color ranges from brown to greenish-brown, mauve and blue. The absorption is very strong except in the blue variety. The size of the grains range from 0.1 mm. to 0.4 mm.

Zircon.—Zircon is present generally as well-rounded, colorless grains, although prismatic grains are not rare. Black, pink, green and colorless inclusions are quite common. The average size of grain is about 0.2 mm.

COMPARISON OF THE HEAVY MINERALS FROM THE NORTH CAROLINA AND FLORIDA AREAS

The same suite of minerals was found to be present in about equal percentages in both areas with the exception of staurolite and epidote. From the analyses it appears that

staurolite is more abundant in the North Carolina area, ranging from 2 to 66 per cent and averaging 35 per cent while in the Florida area staurolite ranges from 1 to 22 per cent and averages 10 per cent.

In the Florida area epidote is more abundant, ranging from 34 to 61 per cent and averaging 43 per cent, while in the North Carolina area it averages only 10 per cent.

The opaque heavy minerals consist essentially of ilmenite, with magnetite and leucoxene in small amounts. They are classed together in the tables principally because of the difficulty of differentiating ilmenite and magnetite in permanent mounts. Ilmenite is the most abundant heavy mineral in both areas.

Shell Matter.—Table 6 gives the percentage by weight of shell material in the samples as determined by leaching with cold dilute HCl. The shell content ranges from 2.94 to 93.53 per cent.

TABLE 6.—*Percentage of Carbonate*

Sample No.	Per Cent Carbonate	Sample No.	Per Cent Carbonate	Sample No.	Per Cent Carbonate
1	6.96	38	12.30	75	14.66
2	12.20	39	8.24	76	24.07
3	15.24	40	3.80	77	15.37
4	6.72	41	17.30	78	30.42
5	18.05	42	12.98	79	22.87
6	8.76	43	27.50	80	15.82
7	18.22	44	5.90	81	15.53
8	16.30	45	5.36	82	25.58
9	26.90	46	7.34	83	15.38
10	36.82	47	24.60	84	26.83
11	8.00	48	13.70	85	13.70
12	10.50	49	6.82	86	21.05
13	6.20	50	13.54	87	19.40
14	10.18	51	15.40	88	14.37
15	6.90	52	6.18	89	55.70
16	9.40	53	13.02	90	30.00
17	14.68	54	2.94	91	17.91
18	34.50	55	31.46	92	12.70
19	15.50	56	48.30	93	21.50
20	4.20	57	8.60	94	10.88
21	14.20	58	48.00	95	45.04
22	19.36	59	32.58	96	19.53
23	21.02	60	32.16	97	31.42
24	26.50	61	7.34	98	80.82
25	20.98	62	19.58	99	45.63
26	9.50	63	20.40	100	57.00
27	14.86	64	8.92	101	13.59
28	32.14	65	4.18	102	48.30
29	15.00	66	27.28	103	10.56
30	26.30	67	26.48	104	44.16
31	15.11	68	42.18	105	44.45
32	11.90	69	27.78	106	18.66
33	14.70	70	21.40	107	—
34	15.36	71	33.30	108	93.53
35	15.90	72	36.90	109	70.07
36	11.20	73	15.28	110	10.82
37	7.12	74	16.40	111	42.72

SUMMARY

1. The most abundant heavy minerals are ilmenite, staurolite, epidote, zircon, garnet, sillimanite, cyanite, hornblende, leucoxene, tourmaline and rutile. Magnetite, hypersthene, apatite, andalusite and monazite are present in small amounts.

2. The same mineral suite is found in both the North Carolina and Florida areas. Staurolite is the most abundant nonopaque heavy mineral in the North Carolina area, while epidote is the most abundant nonopaque heavy mineral in the Florida area.

3. The percentage of mineral constituents shows considerable local variation as is illustrated by hornblende and zircon.

4. The light minerals consist essentially of quartz with a small amount of feldspar and glauconite. Ash and glass are present in varying amounts.

5. The heavy minerals consist in all cases of less than 2 per cent of the entire sample.

6. The shell matter ranges from 2.94 to 93.53 per cent of the samples.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 4, NO. 1, PP. 12–22, TABLE 1, FIGS. 1–4, APRIL, 1934

A PETROGRAPHIC AND PETROLOGIC STUDY OF SOME CONTINENTAL SHELF SEDIMENTS[1]

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ABSTRACT

The results of a study of some detrital and authigenic minerals from the continental shelf off northeastern United States are set forth. A brief analysis of the environment of deposition is presented, and the principles laid down are then applied in a discussion of the resulting deposits.

The study which forms the basis of the present paper is part of an investigation of continental shelf sediments collected off northeastern United States by Mr. H. C. Stetson of the Woods Hole Oceanographic Institution.[2] The writer's purpose was primarily to determine the heavy minerals present, and their distribution. With this done, an attempt was made to use the observed facts to throw light on the source of the material, the manner in which it has reached its present position, and the environment of deposition.

The samples were dredged at intervals approximating one nautical mile along six lines that were run from the shore to the edge of the continental shelf (Fig. 1). The writer did not have access to a sample from every station on the lines, but usually the sediment from second, or third, station was studied petrographically.

A 100 gram fraction of each sample, excepting a few in which the amount available was too small, was used, and the heavy portion isolated in bromoform. The minerals composing this portion were then identified by the Larsen immersionmethod. The Watts system[3] of estimating mineral frequencies was employed to gain an idea of the relative abundance of the various species, and an approximate average of grain sizes was obtained from each sample by measurements with a stage micrometer.

THE MINERALS

The heavy minerals found in the continental shelf sediments are listed in Table 1. Those species, or varieties, represented by a solid black circle are of diagnostic importance in the problem of source and distribution, while those indicated by a circle and enclosed cross are authigenic minerals, locally important as indicators of chemical environment.

[1] Published by permission of the Woods Hole Oceanographic Institution.

[2] Woods Hole Oceanographic Institution, report for the years 1930–1932, pp. 48–49.

[3] Milner, H. B., Sedimentary petrography, p. 386, London, 1929.

TABLE 1. *Showing the Occurrence of the Heavy Minerals, and Indicating the Diagnostic Species*

Minerals	Highland Light	Nauset Light	Martha's Vineyard	Block Island	New Jersey	Maryland
Actinolite			○			
Anatase		○				
Andalusite	●	●	●	●	○	○
Apatite	○	○	○	○	○	○
Augite			○	○	○	
Biotite	●	●	●	●	○	○
Chlorite	○	○	○	○	○	○
Chloritoid	○	○	○	○	○	○
Collophane						○
Cordierite	○					
Corundum			○	○		
Cyanite	○	○	○	○	○	●
Diopside		○	○	○	○	○
Enstatite		○	○	○	○	○
Epidote	○	○	○	○	○	○
Fibrolite	○	○	○	○	○	●
Garnet	○	○	○	○	●	●
Glauconite	⊕	⊕	⊕	⊕	⊕	⊕
Hornblende	○	○	○	○	○	○
Hypersthene	○	○	○	○	○	○
Ilmenite	○	○	○	○	○	○
Iron Sulphide	⊕	⊕	⊕			⊕
Leucoxene	○	○	○	○	○	●
Limonite	○	○	⊕	⊕		○
Magnetite	○	○	○	○	○	○
Monazite				○		
Muscovite	●	●	●	●	○	○
Olivine ?			○			
Rutile	○	○	○	○	○	○
Staurolite	○	○	○	○	○	○
Sillimanite	○	○	○	○	○	○
Spinel			○	○		
Titanite		○		○	○	
Topaz	○	○		○	○	
Tourmaline	○	○	○	○	○	○
Tremolite				○	○	
Zircon	○	○	○	○	○	○
Zoisite	○	○	○	○	○	○

○ Mineral present.
● Mineral of diagnostic importance in problem of distribution.
⊕ Mineral diagnostic of chemical environment.

The plain circles represent detrital species, apparently of no diagnostic value.

The light mineral, quartz, was included in the investigation because of its significance as a constituent of the zone of rounded quartz grains (Fig. 1).

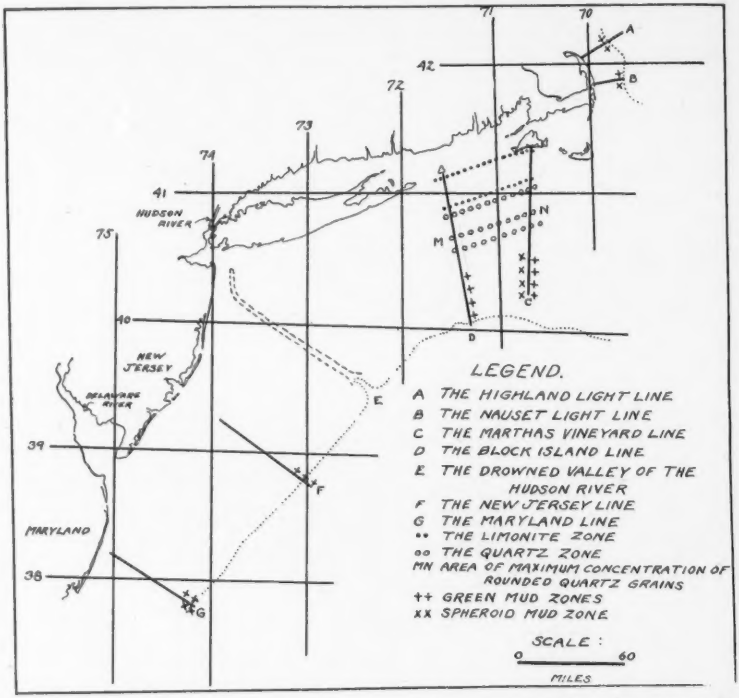

FIG. 1. Map of a portion of the Atlantic continental shelf between Massachusetts and Maryland, showing location of the 100-fathom contour (dotted) and of six lines of bottom samples

THE ENVIROMENT OF DEPOSITION

The most outstanding feature of the coast is the "drowned," embayed shoreline, indicating submergence. Less obvious, but equally good, evidence of a sinking coast, or a rising sea, is furnished by such features of submarine topography as the drowned valley of the Hudson, extending southeastward across the continental shelf from New York harbor[4] and the canyons off Georges Banks, recently described by Shepard.[5] Because of the indicated submergence of the coastal area, it follows, in gen-

[4] Spencer, J. W., The submarine great Canyon of the Hudson River, *Geog. Jour.*, vol. 25, pp. 180–190, 1905.

[5] Shepard, F. P., Canyons off the New England coast (abstract), *Geol. Soc. America*, Bull., vol. 44, p. 99, 1933.

eral, that *if the surface of the continental shelf now departs from the profile of equilibrium, it is most probably below it.*

A sea floor bordering a coastline of submergence should be in a position to receive sediments. The sedimentary materials are being contributed mainly by two agents: (1) the rivers of the region, some of which bring in materials from areas situated hundreds of miles inland, and (2) local marine erosion, indicated by the recession of Cape Cod,[6] Marthas Vineyard,[7] Block Island,[8] and doubtless other localities. Since the contributions of these two agents are available for the establishment and maintenance of a graded profile, deposition must have been active over most of the continental shelf in the geologically Recent past. Deposition is probably taking place over most of the shelf at present, and it is certainly active locally, under such conditions as must obtain during storms.

The distribution of sediments over the shelf is accomplished by currents. While much is known about surficial currents, there is very little published information concerning the bottom ones, although these are of greatest interest to the student of sedimentation. Only one record of the velocity of water at depth was found in the reports of the Coast and Geodetic Survey. This reading was taken approximately 60 miles off the coast of New Jersey, in 144 feet of water, by Dr. H. B. Bigelow.[9] Although the surface water had a velocity of only 0.03–0.05 knots per hour, the reading at depth registered 0.62 knots per hour. Because of the paucity of data concerning the bottom currents, their nature must be largely inferred from observations of the surface, and from a study of the shelf sediments.

Most important of the currents over the continental shelf is an off shore distributional one, which may exist mainly as the resultant of other motions. Locally, it would be reinforced by in-pouring water from rivers. In winter, according to Iselin,[10] the water over the continental shelf may be homogenous in contrast to its usual stratified state, and at this time an on-shore wind will create shoreward-moving surficial currents which return seaward along the bottom. An off-shore wind would, however, bring about a reversal of these conditions. The effect of the off-shore motion is to shift materials seaward and establish a profile of equilibrium, so that any approach to a graded profile is an indication of its existence.

Superposed on the distributional current, a southward moving nontidal stream[11] appears as a disturbing factor, since it doubtless shifts the

[6] Marindin, H. L., Encroachment of the sea upon the coast of Cape Cod, Massachusetts, as shown by comparative surveys: *U. S. Coast and Geodetic Survey, Rept. of Supt.*, Appendix 12, pp. 403–407, 1890.

[7] Shaler, N. S., Geology of Marthas Vineyard: *U. S. Geol. Survey, 7th Ann. Rept.*, p. 358, 1885–1886.

[8] Marsh, O. C., The geology of Block Island: *Am. Jour. Sci.*, 4th ser., vol. 2, pp. 295–298, 1896.

[9] Zeskind, L. M., and LeLacheur, E. A., Tides and currents in Delaware Bay and River: *U. S. Coast and Geodetic Survey, Spec. Pub.* 123, p. 67, 1926.

[10] Iselin, C. O., personal communication.

[11] Patton, R. S., Personal communication.

sediments along the shelf and tends to interfere with the formation of a well graded profile. This stream may locally reinforce the southward moving long shore current, the existence of which is indicated at many places along the coast by the attitude of spits and hooks. The long shore stream may itself be reinforced by tidal currents when these are moving in the right direction.[12]

Besides the off-shore motion and the southward moving tendency, various currents of entirely local character may be important. Considering together the factors that tend to establish a graded profile and those that interfere with this process, it seems that a profile of equilibrium under existing conditions may not be especially well graded. If this reasoning is sound, then it is not safe to say that present conditions over the continental shelf depart greatly from equilibrium.

In addition to the purely mechanical factors involved, some interesting effects of chemical conditions are reflected in the deposits. Along the edge of the continental shelf where current action is doubtless very feeble, and perhaps intermittent, a reducing environment is found in which characteristic sediments are forming. Locally, near shore, in the vicinity of Marthas Vineyard and Block Island, the character of the accumulating sediments seems to indicate oxidizing conditions.

[12] Current Tables, Atlantic Coast of North America: *U. S. Coast and Geodetic Survey*, 1932.

REFLECTION OF ENVIRONMENT IN CHARACTER AND DISTRIBUTION OF THE MINERALS

The effect of the currents noted above is reflected in the distribution of the detrital minerals, including heavy species and the quartz of the zone of rounded quartz grains. The limonite and green mud zones (Fig. 1) are largely results of chemical environment.

Distribution of Detrital Heavy Minerals.—Although thirty-six heavy mineral species and two varieties (Table 1) were identified in the shelf sediments, only six are restricted enough in their distribution, or vary sufficiently in amount from place to place, to be of diagnostic value. It is reasonable to suppose that the mineralogy of the shelf samples would be generally similar throughout, because the crystalline areas of New England, New York, New Jersey, and Maryland are themselves somewhat similar in composition. The six diagnostic minerals are most important exceptions to this general sameness, and can be used to interpret the factors concerned in the distribution of the sediments. Figure 3 shows the frequency of species that are characteristic of northern or southern lines, and of those that vary in amount southward from Cape Cod, or New Jersey.

Andalusite and weakly pleochroic hypersthene, mainly lacking in well-defined schiller structure, are most characteristic of the northern lines, while off New Jersey and Maryland a salmon colored garnet and strongly

pleochroic hypersthene with pronounced schiller structure are certainly diagnostic.

Species that are widely distributed over the shelf, but which vary sufficiently in amount to be considered diagnostic are the following: (1) On the northern lines, andalusite, mica, and weakly pleochroic hypersthene are especially noteworthy. (2) On the southern lines, garnet, hypersthene, fibrolite, cyanite, and leucoxene appear on an average in greater amount than they do on the northern lines.

Doubtless several factors are responsible for the regional variation in kinds and amounts of the detrital heavy minerals that are being shifted outward and swept southward by the currents discussed above. Most important, perhaps, is the drowned valley of the Hudson River (Fig. 1), which serves as a trap to catch materials being shifted southward from the New England shelf. The effect of inpouring Hudson River water in breaking up locally the southward trending currents may be important. This river also carries a fresh lead of sediment, which contributes the possibility of new species in the shelf deposits farther south; a possibility that is realized in the appearance of the salmon-colored garnet and deeply pleochroic hypersthene, which are diagnostic minerals of the New Jersey and Maryland lines. Since both of these minerals were found in a heavy concentrate of beach sand from Port Henry, New York, it seems certain that they have come from the Adirondack region, and have been transported to the ocean by the Hudson.

The local variations in mineral fre-

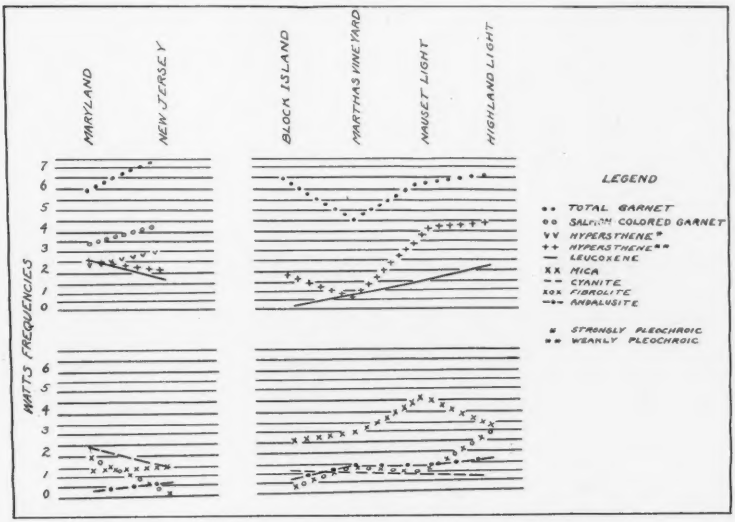

FIG. 2. Diagram showing Watts frequencies of minerals.

quency on the northern and southern lines are of interest. Although garnet and hypersthene are more abundant off New Jersey (near the source of supply from the Hudson River) than off Maryland, cyanite and fibrolite increase greatly in abundance on the Maryland line, because a fresh supply of these two species is contributed by the Delaware River. On the northern lines, perhaps the most outstanding variation is the marked increase of mica in the Nauset Light samples, and the increase in abundance and size of andalusite grains on both of the Cape Cod lines. Since the coast of Cape Cod is undergoing marine erosion, the source of these minerals is doubtless close at hand. Figure 2 shows a considerable drop in the frequency of several heavy minerals on the Marthas Vineyard line. The frequencies reported are the average of all samples studied on a given line, therefore, this decrease must be caused by the presence of the depressed area, covered by fine mud, which is to be found on the outer third of the shelf at this locality (Fig. 3).

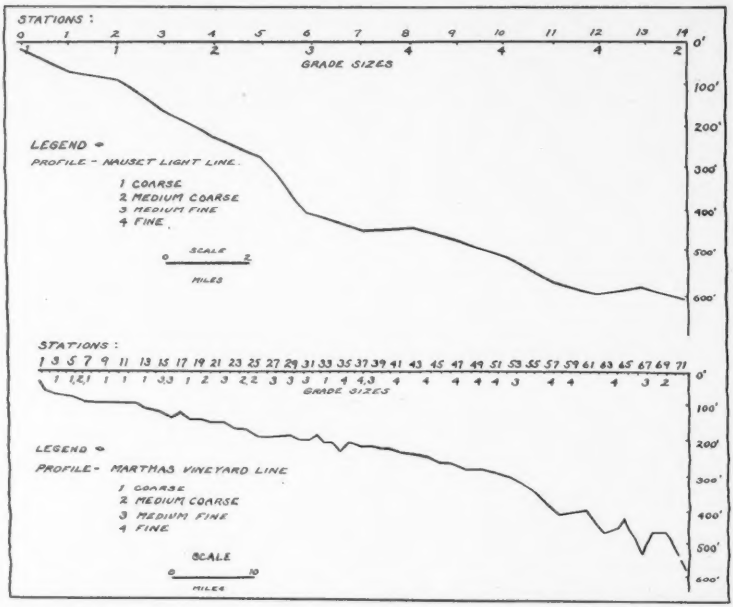

FIG. 3. Diagram showing grade sizes in relation to profile on the Nauset Light and Marthas Vineyard lines.

Zone of Rounded Quartz Grains.—This feature is thought to be remarkable evidence of the power of the current sweeping southwestward from Cape Cod to transport sediments, at

least under proper conditions, such as might obtain during storms. Although the suggestion has been made that the deposit may represent an ancient beach with sand dunes,[13] its position in relation to prevailing currents and possible source of the material (Fig. 1) as well as the character of the deposit make it seem to be a logical result of factors operating at present, in accordance with the principles of deposition from currents.

The zone is found approximately 25 to 45 miles off Marthas Vineyard and Block Island, and is, therefore, about 20 miles in width. The depth of water in which the quartz grains are found varies from 220 to 260 feet, and the maximum concentration occurs at a depth of about 235 feet, near the center of the zone (MN, Fig. 1). The greatest concentration of the grains is, then, directly in the path of the current referred to above. The coarsest grains are also near the center of the deposit, where the broad current by which they are being transported should be strongest. It is also important to note that on the Block Island line, farther from the source of supply, the grain sizes obtained by measurements with the stage micrometer, averaged appreciably smaller than those on the Marthas Vineyard line. This is in agreement with an expectable weakening of the transporting current with increasing distance from Cape Cod.

The material is ill-sorted; large, well-rounded grains being intermingled with small, angular ones. The large grains vary from 0.3 to 1.0 millimeter in size, and the largest ones are usually the best rounded. It is thought that the observed rounding could have taken place on the stormy beaches of Cape Cod. The grains, although clouded with inclusions, are not frosted (Fig. 4A), but frosting, if it formerly existed, could not long withstand the effects of solution.

Distribution of Grade Sizes.—An attempt has been made to obtain the average size of the heavy minerals in each sample studied. Of course, the sizes obtained apply to heavy minerals only, and not to the entire sample, yet they must furnish some indication of what the grades actually were. The terms chosen, and their limits, follow: Coarse, 0.30–0.45 mm.; Medium coarse, 0.20–0.30 mm.; Medium fine, 0.12–0.20 mm.; Fine, 0.05–0.12 mm.

The sizes of the grains were found to correspond most closely with the bottom profile where equilibrium has been most nearly established, as is the case on the Nauset Light line (Fig. 3). Usually, the coarser sedimentary materials occur on the ridges and finer ones in the hollows. This indicates that the ridges are the sites of most rapid deposition from currents moving at some angle to the profile. Where the relation between grade size and bottom topography is the reverse of that stated above, as is occasionally the case, local scouring is believed to be the cause. It is also quite possible that sediment-laden currents may now be flowing between

[13] Stetson, H. C., The sediments of the Continental Shelf off the Northeastern United States (abstract): *Geol. Soc. America, Bull.*, vol. 44, p. 206, 1933.

the ridges in some places, and depositing coarser detritus there.

The Limonite Zone.—This zone is approximately 15 miles wide, and is directly off the shores of Marthas Vineyard and Block Island (Fig. 1). The depth of water in which the limonite was found varies from 60 feet to more than 200 feet.

The material occurs as pellets and plates, sometimes constituting as much as 40 per cent of the heavy mineral fractions. The general character of the grains is shown in Figure 4B, in which it can be seen that a gradation exists from forms possessing a distinctly micaceous structure (partially altered biotite), to grains that are spherical or elliptical in shape. The partially altered biotite flakes often have thick rims (not shown in Fig. 4B), the next stage being loss of the plate-like character and development of saucer shaped forms. The well rounded limonite pellets that are the final product, are dark red-brown in color and possess a high polish.

It is thought that these bodies have been formed mainly *in situ*, by the alteration of biotite. The biotite is assumed to have been brought to its present resting place in a partly oxidized condition; then completely limonitized. Examination of partially limonitized pellets discloses a center composed of biotite with an optic axial angle of almost zero. This angle increases toward the periphery of the grain until it reaches about 40 degrees, beyond which the biotite structure seems to break down completely, and limonite results.

The morphological changes are as remarkable as those of internal structure. Swelling of the rim, the earliest stage observed in the alteration to limonite, is easily understood as a physical result of oxidation and hydration at the edges of the flakes. As swelling proceeds, tension is set up in the center, and the flake tends to buckle

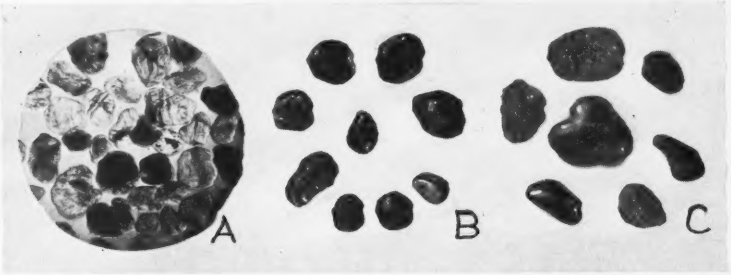

FIG. 4A. Rounded grains from the quartz zone, Marthas Vineyard line, 38 miles off shore; ×22, transmitted light.
FIG. 4B. Some later stages in the alteration of biotite, Block Island line, 7 miles off shore; ×22, reflected light.
FIG. 4C. Later stages in the formation of glauconite, New Jersey line, 80 miles off shore; ×22, reflected light.

away from that side on which the tension is the greater, so that a saucer-shaped form results. A general thickening, accompanied by further rolling up, continues as the process goes to completion, so that the final shape is pellet-like, with no suggestion of the former platy character. Abrasion may possibly account for some of the rounding, but it is doubtful that the high polish, characteristic of the finished grains, is the result of movement over the bottom. Some stalactitic and betryoidal forms of limonite are characterized by shiny varnish-like surfaces, and it is thought that the limonite grains found on the continental shelf may owe their polish to the formation and subsequent hardening of a gel-like hydrosol around the pellets in the closing stage of development.

The geologic map of Rhode Island and Connecticut shows the ancient crystalline rocks of that area to contain several biotite-rich types,[14] which would provide an adequate source of mica to be altered in the limonite zone, and since partly altered biotite is found on the shoreward side of the limonite deposit, there can be little doubt that the required, already partly oxidized, mica has been and is being derived from the rocks directly north. Rivers, such as the Narragansett bring the material to the sea, and tidal currents,[15] effect a distribution over the limonite zone. On the seaward side, fresh biotite flakes that have drifted in from the northeast, probably from Cape Cod, are found with the limonite pellets.

The Green Mud Zone.—The outer edge of the continental shelf, especially in the vicinity of the 100-fathom curve, is characterized by the presence of glauconitic mud. The color of the mud indicates a reducing environment, probably favored by weakness of current action over this portion of the shelf, with consequent partial stagnation. In many cases, half of the sample consisted of foraminifera, of which the most abundant species belonged to *Globigerina*, a pelagic genus, although several types of bottom-dwellers were also present. The abundance of organic matter, some of which must always be in process of decay, doubtless helps to maintain a reducing environment, although, in general, the conditions cannot be extremely toxic.

There are three important inorganic constituents in this zone: (1) green mud, (2) iron sulphide bodies, and (3) detrital material.

The green color of the mud is believed to be caused by the partial reduction of ferric iron, present as sulphate or hydrosol, according to Hadding.[16] The result is considered an incipient stage in the formation of glauconite. Some more advanced stages are recorded by dull, green lumps, with surfaces traversed by a network of cracks and finally by black, shiny grains, on some of which

[14] Emerson, B. K., Geology of Massachusetts and Rhode Island: *U. S. Geol. Survey, Bull.* 597. 1917. Gregory, H. E., Preliminary geological map of Connecticut: *Conn. Geol. and Nat. Hist. Survey, Bull.* 7, 1907.

[15] LeLacheur, E. A., and Sammons, J. C., Tides and currents in Long Island and Block Island Sounds. *U. S. Coast and Geodetic Survey, Spec. Pub.* 174. pp. 1–187, 1932.

[16] Hadding, A., Glauconite and glauconitic rocks: *Lund Geol. Min. Inst.*, Pt. 4, p. 155, 1932.

traces of cracks are still preserved (Fig. 4C). The formation of the polished surfaces is probably caused by the hardening of a gel, a process identical to the one appealed to in accounting for the polish on the limonite grains.

The cryptocrystalline character of the material made it impossible to refer measured indices of refraction to to the definite vibration directions, α, β, and γ. The highest index found was 1.638, the lowest 1.623, but it is not certain that these represent the true maximum and minimum.

The iron sulphide bodies are commonly tiny spheroids, invariably found enclosed in the shells of foraminifera, where they have doubtless been formed under the intense, local reducing conditions consequent upon decay of the organic matter within the minute tests. The distribution of the spheroids is shown in Figure 1. On some of the lines, there are occasional rod-like forms, that may have been deposited in worm burrows.

Although green mud usually forms the greater part of the sedimentary material on the outer part of the shelf some coarser detritus is present. A part of this material may have been floated seaward as grains embedded in jelly-like masses, as described by Raymond and Stetson.[17] However, some of the detrital material of the green mud zone on the northern lines reaches pebble size, and for this reason it is thought that floating ice may have, in Recent time transported some sediment to this zone.

[17] Raymond, P. E., and Stetson, H. C., A new factor in the transportation and distribution of marine sediments: *Science, n.s.*, vol. 73, pp. 105–106, 1931.

SUMMARY

The continental shelf is probably slightly below the profile of equilibrium, although it may locally have attained this condition. It has been a site of active deposition in the geologically recent past, and doubtless continues to be so.

The distribution of the detrital minerals reveals the effect of the southward-moving currents, and gives a clue to the source of some of the sediments. A study of the grade sizes reveals an approach to the profile of equilibrium, which, under existing conditions, is not necessarily a well-graded profile.

Observed stages in the alteration of biotite indicate that most, if not all, of the limonite off Block Island and Marthas Vineyard is authigenic, and the distribution of the material suggests a source close at hand.

Some stages in the formation of glauconite were observed in the green mud zone at the edge of the shelf. The reducing conditions under which the glauconite forms have also favored the development of iron sulphide. The coarse detritus in the green mud zone has probably been floated out in gel-like masses, or in ice.

In addition to acknowledging the aid received from his committee at Cornell University, the writer wishes especially to thank Mr. H. C. Stetson, Dr. P. E. Raymond, Dr. E. S. Larsen, and Dr. H. B. Bigelow for assistance in carrying this study to completion.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 4, NO. 1, PP. 23-31, PLS. 1-3,
APRIL, 1934

THE OCCURRENCE OF AUTHIGENIC FELDSPARS IN SEDIMENTS[1]

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ABSTRACT

Authigenic feldspars in sediments have been reported by a number of workers from many geologic horizons, but the opinion prevails that such feldspars are relatively uncommon. Most investigators have concluded that the authigenic growths occurred during the deposition or early consolidation of the containing sediments. The authors have studied a large number of thin sections and insoluble residues and conclude that authigenic feldspars occur in many types or rocks from Cambrian to Cretaceous in age, and that in certain instances the evidence indicates that growth occurred after consolidation of the rock and during a period of replacement by meteoric waters. Feldspars are common in limestone and dolomite, and in some arenaceous beds the feldspar is known to constitute about 30 per cent of the fine grades.

The existence of secondary feldspars in sediments has been known since 1861 when Drian[2] and Lory[3] described the occurrence of feldspars in limestones from the Alps. Rose[4] later described in detail the same material as 'Roc Tourne' twins of albite. Drian and Lory concluded in their separate papers that the feldspars were formed as secondary products before the consolidation of the calcareous muds and not by subsequent metamorphic processes.

In the years following 1861 many workers in different parts of the world have described secondary feldspars. In the majority of cases the feldspars that were described comprise a very small portion of the rock and their occurrence has been considered an oddity rather than a normal development. The work done by the Europeans shows albite as the most common feldspar of secondary origin, with orthoclase abundant in certain horizons. It is needless to review in detail the progress of this work as Twenhofel,[5] Boswell,[6] and others have discussed adequately the work

[1] Presented at Chicago meeting, Geological Society of America; Abstract in *Geol. Soc. America, Bull.*, vol. 45, in press.

[2] Drian, A., Notice sur les cristaux d'Albite renfermés dans les calcaires magnésiens des environs de Modane: *Soc. Geol. France, Bull.*, 2d ser., vol. 18, pp. 804–805, 1861.

[3] Lory, C. Comptes rendus d'une excursion geologique dans la vallee d'Entremont (Savoie): *Soc. Geol. France, Bull.*, vol. 18, pp. 806–826, 1861.

[4] Rose, G., Über die Krystallform des Albits von dem Roc-Tourne und von Bonhomme in Savoyen und des Albits in Allgemeinen: *Pogg. Ann. Phys. Chem.*, vol. 125, pp. 457–468, 1865.

[5] Twenhofel, W. H., and others, Treatise on sedimentation, 2d edition, pp. 591–596, 1932.

[6] Boswell, P. G. H., On the mineralogy of sedimentary rocks, T. Murby and Co., pp. 87–96, 1933.

to this date and the reader may refer to these books for a complete bibliography.

Most of the published conclusions favor an origin other than that due to metamorphism or igneous activity, but in most cases this is due to the absence of any direct evidence in either direction. A common hypothesis proposed for conditions of formation is that growth occurred on the sea floor during a period of slow sedimentation. Grandjean[7] suggests that the feldspar growth stopped at the time of burial by new sediments. Miss Reynolds[8] attributes growth on the sea floor to the absorption by kaolin or clay of potash from the sea water. The best evidence for growth during deposition appears to be in the nature of the inclusions often found in the feldspar. A number of investigators report carbonaceous matter, clay particles or less commonly small fragments of calcite or dolomite included in the glassy clear crystal forms of albite and orthoclase. However, the authors believe that clay particles or carbonaceous materials are usually available for inclusion by secondary minerals from a rock in any stage of consolidation prior to complete recrystallization. The average limestone and practically all clastic rocks contain sufficient dust-like particles of clay and carbonaceous material to furnish that for inclusions.

With the possible exception of de Lapparent[9] no one has recognized any evidence to favor the growth of secondary feldspars after early consolidation of the rock or accompanying recrystallization of the calcite or dolomite. It is true that with this time of growth one might suspect hydrothermal activity, and in each case of the occurrences described by Schmid,[10] LaCroix,[11] Borisov,[12] and Baturin[13] there are other minerals present which either suggest or are definitely of hydrothermal origin. The possibility is still open, however, that normal sedimentary processes of consolidation and cementation might also permit the growth of secondary feldspars. In this discussion the authors will present evidence to establish this belief.

Definition of Terms.—The numerous occurrences of secondary and detrital feldspar already described in the literature suggest that the simple statement that feldspar occurs in a sediment is not sufficient and that care should be exercised in sedimentary petrography to differentiate between detrital and secondary minerals. Further caution is suggested in

[7] Grandjean, F., Le feldspath neogene des terrains sedimentaires non-metamorphiques: *Bull. Soc. franc. Min.*, vol. 32, pp. 103–133, 1909, and vol. 33, pp. 92–97, 1910.

[8] Reynolds, D. L., Some new occurrences of authigenic feldspar: *Geol. Mag.*, vol. 66, pp. 390–399, 1929.

[9] de Lapparent, J., Leçons de petrographie, Paris, pp. 343, 378–379, 1923.

[10] Schmid, E. E., Das ostthuringische Roth: *Jahrb. Pruess. geol. Landesanst*, pp. 92–156 (esp. pp. 100–102), 1882.

[11] LaCroix, A., Notes sur quelques mineraux français. 1. Albite de Pouzac (Haut Pyrenees): *Bull. Soc. franc. Min.*, vol. 11, pp. 70–71, 1888.

[12] Borisov, P. A., Crystals of silicates in the dolomites near the town of Poventsa: *Acad. Sci. Russ., Bull.* Petrograd, vol. 11, 6th ser., pt. 2, pp. 1289–1314, 1917. (From abstract in *Min. Abstr.*, vol. 2, p. 125.)

[13] Baturin, V. P., (French Summary) Sur l'Albitisation de quelques Roches Sedimentaires dans la Region de la route Militaire de Georgie: *Bull. Com. Leningrad*, vol. 47, pp. 55–63, 1928.

the recognition of true authigenic minerals as distinct from secondary enlargement of detrital grains. Each condition may have a different interpretation.

For purposes of proper understanding it is desirable to give a brief definition of the terms as used in this paper. An *authigenic mineral* is one which is formed as a crystallographic unit at the place of its occurrence by sedimentary processes (pl. 1, figs. 1–13 incl., and pl. 3, figs. 3, 4, 5, 7). There may be more than one period of authigenic growth, and there may or may not be a nucleus; if a nucleus to the first period of authigenic growth is present it is of detrital origin (pl. 1, figs. 4–7). Another type of process is called *secondary enlargement* and in accordance with the precedent set by Van Hise,[14] growth of this type is always around a nucleus of the *same* material and *with optical continuity* (pl. 1, figs. 15, 17 and 18). Both of these forms are secondary; that is they develop after deposition of the nuclear grain or the enclosing rock.

Secondary enlargement is not uncommon in feldspars. Some grains show a nucleus surrounded by new material in perfect optical orientation and even with twinning bands continuing through the secondary zone; these grains are produced by secondary enlargement of pre-existing grains of detrital or authigenic origin. In other cases, often in the same rock, the secondary material does not have the same optical orientation as the nuclear grain, or it may be of a different composition; such a case is a true authigenic growth as it lacks either a mineralogical or optical relation to the nucleus. Thus, the distinction between grains of authigenic growth which have a nucleus and are of the same mineral composition, and those of secondary enlargement hinges on the optical orientation of the secondary material. This differentiation may seem to be of minor importance but it is deemed advisable to distinguish two types of growth which may be produced by distinctly different processes.

Many of the authigenic feldspars described by various writers during the last few years appear to be due to secondary enlargement. Both secondary types may occur in the same rock and it is possible that the enlarged types are more common than the true authigenic variety. However, closer studies may show that it is difficult to obtain the special set of conditions of proper optical and crystallographic orientation and correct composition of the secondary material necessary for secondary enlargement.

Methods Used in Study.—The methods used in the studies of the various rocks containing feldspar are well known and therefore, will be described only briefly. To obtain the insoluble residues of the calcareous specimens small chips of the rock which have been broken carefully (not crushed) are treated in dilute (15 per cent) hydrochloric acid.

[14] Van Hise, C. R., Enlargement of feldspar fragments in certain Keweenawan sandstones: *U. S. Geol. Survey, Bull.* 8, pp. 44–47, 1884; and Treatise on metamorphism: *U. S. Geol. Survey,* Mon. 47, pp. 625–626, 1904.

Whenever it is necessary to resort to heating the preparation the maximum temperature is not allowed to go above 150° C and this only when the rock is dominantly dolomite. After a careful washing to remove all traces of acid the insoluble residue is caught on a filter paper and dried. Some of the friable arenaceous specimens were not treated with acid. In some cases it was found advantageous to sieve the material to obtain in-

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PLATE 1. Photomicrographs to illustrate types of secondary feldspar.

(Magnifications approximate to nearest even value. All grains mounted in balsam).

FIG. 1.—Authigenic adularia around microcline nucleus. Euhedral outline of adularia indistinct due to thinness of edge. Cross-nicols; ×300.

2.—Same grain as figure 3, shows nucleus of microcline and albite surrounded by adularia. Cross-nicols; ×300.

3.—Authigenic adularia showing euhedral outline. Same grain as figure 2. Border of nucleus shows impurities of carbonaceous material and iron oxide adhering to surface of original grain. Minor inclusions of same impurities in authigenic growth. No nicols; ×360.

4.—Two periods of authigenic growth. Nucleus untwinned and of unknown composition, curvilinear shape; first growth of albite with distinct twinning bands distorted where they pass over and under the nucleus; second authigenic growth of adularia showing on right side and top of grain, untwinned; the edge of albite suggests abrasion or solution. Cross-nicols; ×200.

5.—Same grain as figure 4, shows partial development of euhedral boundaries and faint outline of abraded nucleus and of authigenic albite. No nicols; ×360.

6.—Same grain as figure 7, shows clearly the boundaries described for figure 7 and the fairly distinct euhedral outline of adularia. Most of the included impurities belong to the last period of growth. No nicols; ×360.

7.—Two periods of authigenic growth. Same grain as figure 6. Abraded nucleus of albite (?) surrounded by border of albite of first growth which is fresh and unabraded and surrounded by authigenic adularia of second period of growth. Cross-nicols; ×300.

8.—Same grain as figure 9. Authigenic growth of adularia around a clastic grain showing microcline and albite twinning. Cross-nicols; ×225.

9.—Same grain as figure 8. Note few inclusions of calcite in adularia. Scalloped margin due to incomplete growth in contact with surrounding crystalline carbonates of rock. No nicols; ×280.

10.—Well developed euhedral adularia growth around indistinct orthoclase clastic nucleus. No nicols; ×180.

11.—Authigenic growth of albite, showing flattening along 'a' axis. Note angular indentations in margin at top which are due to growth around dolomite rhombs of rock. No nicols; ×280.

12.—Authigenic albite showing flattening along 'a' axis. Well developed euhedral outline; numerous inclusions of a carbonate, organic material and a liquid (?). No nicols; ×280.

13.—Authigenic microcline without a nucleus; euhedral outline incomplete, margins notched and fringed due to growth displacing carbonates of rock. Inclusions in center of grain. No nicols: ×280.

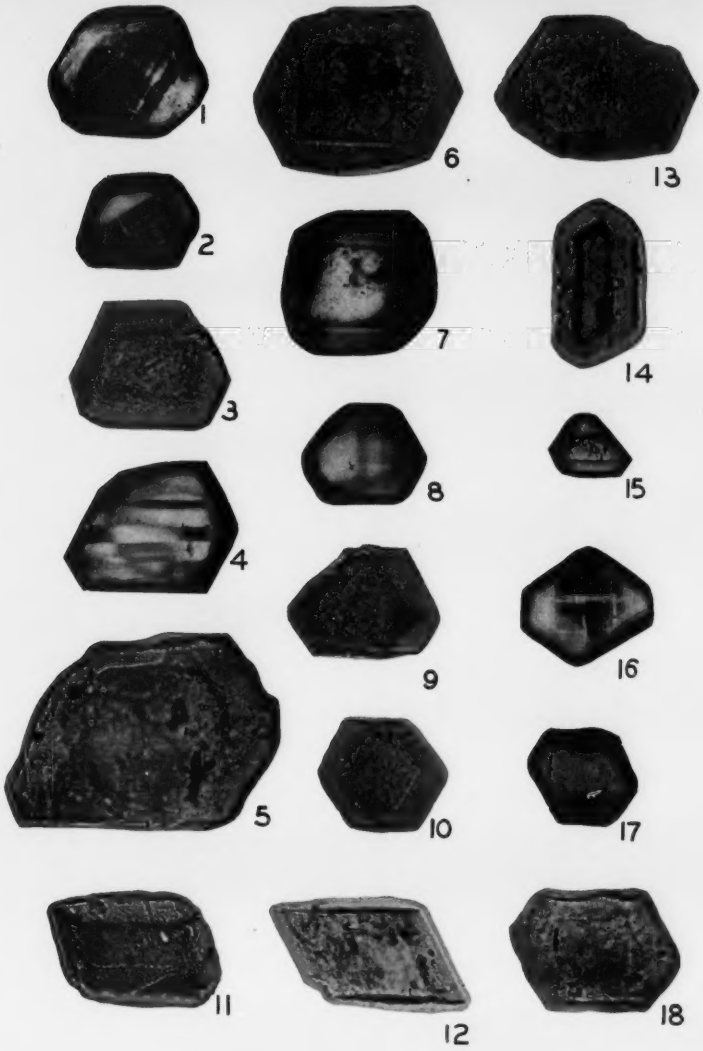
14.—Authigenic adularia grown around a nucleus heavily coated with iron oxide. The iron suggests a growth *after* the period of iron staining of dolomite rhombs described in 3*c* of stages in history of rock (p. 000). Note also the angular indentations in margin due to growth in contact with rhombic dolomite. No nicols; ×360.

15.—Secondary enlargement of adularia. Note partial coating of iron oxide on nucleus. Cross-nicols; ×150.

16.—Authigenic twinned microcline nucleus with second period authigenic microcline with 18° angle between extinction positions. Cross-nicols; ×100.

17.—Secondary enlargement of adularia. Same grain as figure 18. Note euhedral outline of older grain with very faint indication of a rounded nucleus. Last growth shows optical continuity with first growth and the questionable nucleus. Cross-nicols; ×300.

18.—Same grain as figure 17, No nicols; ×360.



Tester and Atwater—Authigenic feldspars

dividual size grades. The light and heavy minerals were separated by bromoform with a centrifuge and in some cases the quartz and feldspar were separated by carefully controlling the gravity of the bromoform. Mounts in balsam were made of a part of each fraction and all the material was studied with a petrographic miscrocope.

In addition, the limestone and dolomite specimens and some sandstones were thin-sectioned for petrographic examination. This procedure is necessary to establish the full history of the rock and is considered to be a very important part of such an investigation.

Geologic Range of Material Studied. —With these points of classification and origin in mind the authors have studied a large number of thin sections and insoluble residues of sediments dating from Early Cambrian to Late Cretaceous age. Both types of secondary feldspar were encountered and in several of the Lower Paleozoic rocks a surprisingly large amount of authigenic feldspar was seen. It is safe to say that authigenic feldspar occurs in every system of the Paleozoic at some locality. Even with such a wide stratigraphic range, authigenic feldspar can be used to differentiate horizons as it frequently occurs as a "flood" mineral in the lighter fractions of a mineral separation.

The senior author has examined a large number of mineral concentrates of the arenaceous and calcareous rocks of the Cambro-Ordovician section of the Upper Mississippi Valley in connection with the petrologic studies that have been and are being made by a number of graduate students at the State University of Iowa. Authigenic feldspar has been observed in the Dresbach, Franconia, St. Lawrence and other formations of numerous localities of Minnesota and Wisconsin. About 50 feet above the base of the Franconia at the type section approximately 30 per cent of the sand is authigenic feldspar in grains $\frac{1}{8}$ to $\frac{1}{16}$ mm. size. At a number of localities along the St. Croix River the St. Lawrence contains 10 to 15 per cent of authigenic feldspar. In the Jordan sandstone authigenic feldspar is rare but numerous grains of secondarily enlarged feldspar have been seen. The Prairie du Chien formation contains an abundance of authigenic feldspar at several horizons; at Stillwater the euhedral forms of adularia are especially well developed. The occurrences of feldspar in the Decorah and Galena formations will be discussed later.

The junior author[15] has been able to differentiate uppermost Keweenawan formations of northeastern Minnesota from the Mt. Simon member of the Dresbach formation on the basis of different types of secondary feldspar.

In connection with other work the senior author has studied authigenic and secondarily enlarged feldspar in the Niagaran limestone of eastern Iowa; in the Cedar Valley limestone

[15] Atwater, G. I., and Clement, G. M., Pre-Mt. Simon age of the Hinckley sandstone (Abstract): *Geol. Soc. America, Bull.*, vol. 45, in press.

near Iowa City and Chemung formation of western New York, both of Devonian age; in several Mississippian limestone beds of Iowa; in Lower Pennsylvanian sands of Iowa; in Upper Permian dolomite of central Kansas; in the Mentor sandstone of late early Cretaceous age in central Kansas; in the Dakota sandstone of the type locality; in the Greenhorn limestone of Barton County, Kansas and in the Niobrara type section, both of Late Cretaceous age. Such a general occurrence emphasizes the need for a study of the entire mineral content of a rock. Feldspars are usually missed when a study is made of only the heavy minerals.

Time of Feldspar Growth.—Little direct evidence has been presented to establish the time of formation of the secondary feldspars. Some workers have suggested that the feldspar was formed on the sea bottom at the time of deposition of the enclosing sediment, and de Lapparent[16] suggests that the algae of the Flysch limestones of the Pyrenees were instrumental in causing the formation of the feldspar crystals, but believes that the feldspar had been produced at the time the rocks acquired their crystallinity.

That authigenic feldspar could be produced after the deposition and consolidation of a sediment has few supporters. In the case of the feldspar of the Decorah and Galena formations the evidence favors the conclusion that the feldspars were formed after deposition and cementation by calcite and during or after a period of secondary dolomitization.

The stages in the history of these rocks are summarized in brief as follows:

1. The Decorah (Guttenberg and Ion) *limestones* were deposited as coquinas with a minor amount of abraded and angular detrital quartz and feldspar. This material was cemented by anhedral calcite and by a calcareous mud (*pl. 2, fig. 1*).

2. (*a*) Parts of the coquina and matrix of the Decorah were recrystallized into irregular masses of dolo-

[16] de Lapparent, J., Sur les cristaux de feldspathes developpes dans les Calcaires du Cretare Superieur Pyreneen: *Compt. Rend., Paris, Acad. Sci.*, vol. 167, pp. 784–786. See also pp. 999–1001, 1918.

PLATE 2. *Photomicrographs of thin sections to illustrate time and conditions of* authigenic feldspar formation.

FIG. 1.—*Coquina of Decorah formation cemented by fine calcite mosaic. Stage 1 of history.* No nicols; ×16.

2.—Growth of dolomite mosaic which obliterates fossil structures and coquina nature of *rock. Decorah formation; stage 2a. No nicols;* ×20.

3.—Concentration of dolomite rhombs in solution channel of Galena formation. The channel is distinguished by dark area with grains 'floating' in it; stage 3b. Polarizer *only;* ×16.

4.—Part of solution channel shown in figure 3. Note numerous dolomite rhombs surrounded by iron oxide. Authigenic feldspars occur in this zone. Galena formation. Cross-nicols; ×66.

5.—Group of authigenic feldspars (adularia and albite) concentrated from insoluble residue of Decorah *formation, mounted in balsam. No nicols;* ×285.

6.—Dolomite rhombs showing secondary enlargement and iron staining, floating in clear anhedral calcite; stage 6. Upper Decorah *formation. No nicols;* ×16.

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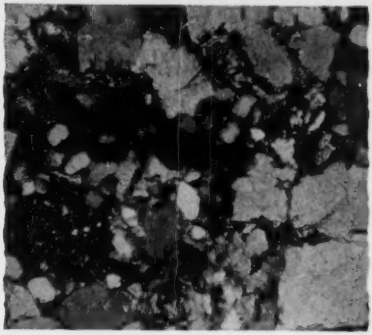

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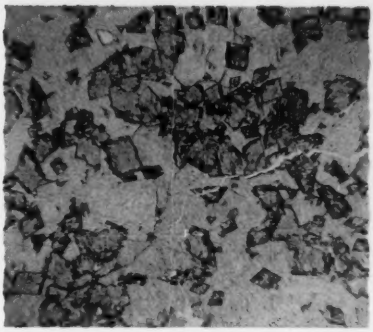


6

Tester and Atwater—Authigenic feldspars

mite and calcite with a mosaic texture which obliterates fossil structures. This mosaic is distributed irrespective of deposition or laminae and hence is not the original precipitate (pl. 2, fig. 2).

(*b*) In the specimens of Galena dolomite are shell fragments scattered sparsely in a mosaic of anhedral dolomite. If a coquina existed at this horizon it is now almost completely destroyed and the existence of a primary coquina cannot be proved. Therefore, the dolomite mosaic may represent the original texture of the precipitate.

3. (*a*) The formation of dolomite rhombs, which destroyed all textures previously formed, including the dolomite and calcite mosaic (of 2), the coquina or calcareous mud (pl. 3, fig. 6).

(*b*) In the Galena, the rhombs of dolomite are scattered in the mosaic, or concentrated along branching solution channels (pl. 2, figs. 3 and 4).

(*c*) In the upper part of the Decorah limestones there are areas of iron-stained dolomite rhombs which are later than stages 1, 2 and 3, and possibly later than 4 (pl. 3, fig. 1). The rhombs show at least two periods of growth. A concentration of iron oxide borders the inner or early crystal and this is surrounded by a second zone of dolomite which also frequently shows a border of iron oxide.

4. The feldspar developed either as secondary enlargement or as authigenic growth with or without a nucleus. In a few isolated cases the authigenic growth was around a secondarily enlarged grain and in other cases there were two stages of authigenic growth (see pl. 1).

In the Decorah limestone the feldspar crystal growths occurred most readily in the mosaic dolomite and calcite (pl. 3, fig. 8). They developed also in the coquina part of the limestone as they are found within the shell structure (pl. 3, fig. 2). Therefore the recrystallization of the coquina was not essential for the growth of the feldspar.

In the Galena dolomite or the dolomitized Decorah limestone the feldspar formed most readily along the solution channels (pl. 2, fig. 4), but is also developed in lesser concentrations throughout the mosaic.

This relation of the growth of the feldspar crystals to periods of recrystallization in the Decorah and Galena definitely determines the origin of the feldspar, and they cannot represent crystal growth contemporaneous in age with the deposition of the carbonate on the sea floor, as has been believed by some writers for other occurrences. The feldspar must have developed subsequent to the lithification of the sediment and at a stage intermediate in the late history of the rock.

5. Contemporaneous with or closely following the formation of the feldspar, authigenic quartz with doubly terminated pyramids was formed and a silification of some of the shells occurred. The silification usually inherited the wavy or crenulated structure of the shell, but in some cases the shell structure was destroyed and a mosaic or spherulitic chalcedony

was developed (pl. 3, fig. 10). Chalcedony is also found in minor amounts independent of shell structures.

6. At a somewhat later stage occurred the introduction of clear anhedral calcite which formed in fractures and veins and recrystallized the bordering mosaic dolomite and calcite. The iron-stained dolomite rhombs and the authigenic feldspar are floated in this calcite (pl. 2, fig. 6, and pl. 3, fig. 9).

Varieties of Feldspar Observed.—The minerals occurring as nuclear grains are of the potash and plagioclase classes. Orthoclase, microcline, albite and labradorite have all been observed and there is no reason why every variety of plagioclase should not occur if the nuclear grains are of detrital origin.

The secondary feldspar of an enlarged grain is of the same variety as the nucleus. Enlargement as observed by the writers is confined to the orthoclase, microcline and albite varieties.

The authigenic growths, as defined previously, may occur on a grain of any variety or without an apparent nucleus. As determined by a study of optical properties the most common authigenic feldspar is adularia; albite and microcline are relatively rare. Characteristic forms of adularia may be seen in plate 1, figures 3, 9, 10, and 18, and typical albite in plate 1, figures 11 and 12, and plate 3, figure 4, and both forms occur in plate 2, figure 5.

Conditions of Growth.—As has been indicated previously in this discussion certain European workers attributed the formation of authigenic feldspar to hydrothermal activity. There is no evidence in the material studied,

PLATE 3. Photomicrographs of thin sections to illustrate time and conditions of authigenic feldspar formation.

FIG. 1.—Iron stained dolomite rhombs of upper Decorah formation; shows two periods of staining and a secondary enlargement of dolomite; stage 3c. No nicol; ×60.

2.—Authigenic feldspar grown in zooecial cup of a bryozoan that is partially replaced by calcite mosaic; Decorah formation. No nicols; ×127.

3.—Authigenic adularia around microcline nucleus; glauconite in contact on left and base. Almost in contact at base of feldspar is a secondarily enlarged quartz grain. Top of St. Lawrence formation, Stoddard Quadrangle, Wisconsin. (08043). Cross-nicols; ×106.

4.—Authigenic albite around large indistinct nucleus. Shows one cleavage which extends from nucleus to secondary zone but other cleavage is not developed in authigenic part. Same thin section as figure 3. No nicols; ×250.

5.—Two authigenic feldspar grains. Grain at top shows abraded nucleus and typical euhedral outline of adularia; lower grain is albite and shows cleavage. Same thin section as figure 3. No nicols; ×250.

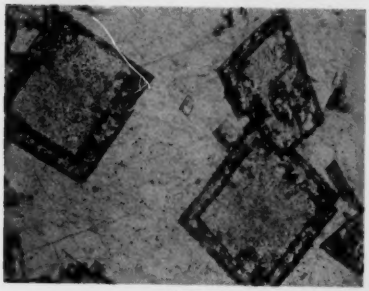
6.—Growth of dolomite rhombs in mosaic of dolomite and calcite modifying the previous texture. Decorah formation, stage 3a. Polarizer only; ×18.

7.—Authigenic albite around nucleus of albite. Twinning in secondary zone shows different position from that of nucleus. Same thin section as figure 3. Cross-nicols; ×140.

8.—Growth of authigenic feldspar in mosaic and rhombic texture of dolomite of Decorah formation; stage 4. Polarizer only; ×60.

9.—Chalcedony with inherited crenulated structure of shells and in spherulites of stage 5 being replaced by vein calcite of stage 6. Upper Decorah formation. Cross-nicols; ×60.

10.—Silicification of shells with inheritance of crenulated shell structure; stage 5. Decorah formation. Cross-nicols; ×60.



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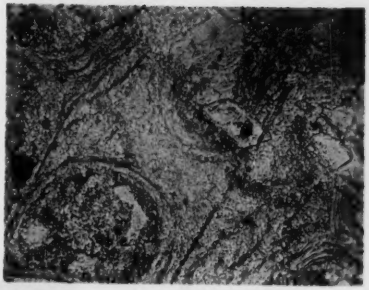

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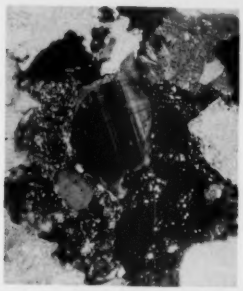

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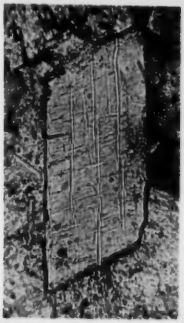

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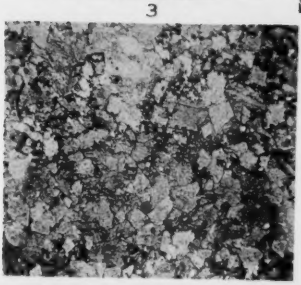

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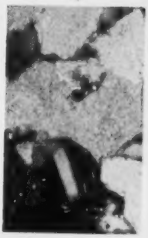

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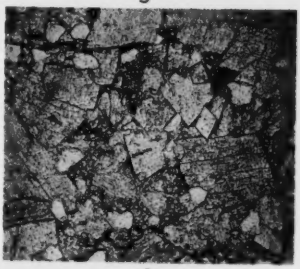

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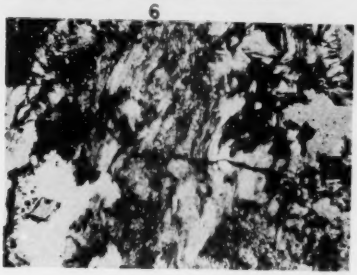

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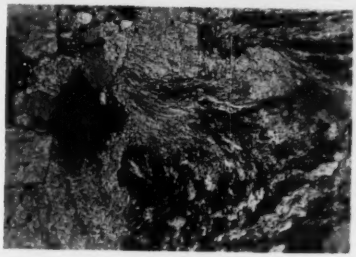

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either in the mineralogy or textural relations, that could be used to support such a hypothesis in this case. There are no minerals that ordinarily accompany hydrothermal metamorphism associated with the development of the calcite mosaic, dolomite rhombs, silicification of shells or formation of authigenic feldspar. Some might suspect the period of silicification as indicative of metamorphism, but there is no direct proof that such is the case. The glauconite and clay of the rock are essentially unaltered and one would expect these minerals to be the first to change under the influence of hot solutions.

Considering the subject of secondary feldspar from a general viewpoint, the wide stratigraphic range and geographic distribution of the known occurrence in the central interior of the United States argues against an origin by any means other than normal sedimentary processes. The writers are not opposed to the consideration of hydrothermal activity in the areas of the rocks studied, but believe that positive and direct proof must be obtained to favor such a hypothesis against the evidence seen in the material submitted here.

CONCLUSIONS

1. The authigenic minerals, which are formed, in situ, by sedimentary processes, are distinguished from the secondarily enlarged grains with optical continuity, whose origin is not limited to sedimentary processes.

2. Attention should be paid to the minerals of low specific gravity in the insoluble residues.

3. Thin section study of a consolidated rock is necessary for a complete knowledge of history and origin of the constituents.

4. Secondary feldspar is not uncommon, but has a wide geologic and geographic distribution.

5. In the case of the Decorah and Galena formations the secondary feldspars were formed considerably later than deposition and original consolidation and probably at a late stage in the history of the rock. Such a period of growth should not be inferred for all cases of secondary feldspar, but it is probably more common than usually considered.

6. In the material studied, there is no evidence of hydrothermal activity to answer the question of origin.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 4, NO. 1, PP. 32–35, FIG. 1,
APRIL, 1934

A HIGH INDEX REFRACTOMETER

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ABSTRACT

A cleavage fragment of smithsonite of known refractive indices is mounted permanently in a hole in a microscope slide. The cavity is filled with liquid of high but otherwise unknown index and covered with a cover glass. The slide is then mounted on a universal stage equipped with a water cell for temperature control. The crystal is rotated in such a way that its principal section remains parallel to the polariser. When the indices of the crystal and liquid agree the amount of rotation from the optic axis position is used as the ordinate of a graph—the abscissa gives the refractive index. Proximate curves serve to indicate dispersion.

The Abbé refractometer of standard manufacture measures refractive indices as high as 1.70 or 1.71 with an accuracy of $\pm .0002$ except at the higher end of the scale where the liquid approaches the glass prism in refractive index and the boundary between the light and dark field becomes less sharp. The Spencer Lens Co. has manufactured two Abbé refractometers for higher indices, one reading to 1.79 and the other reading to 1.84. Both of these were produced in a spirit of laudable cooperation in response to the demands of the profession but are characterized by inherent limitations admitted by the manufacturer and apparently unavoidable in instruments of the sort. They are (1) The glass used in the prisms is yellow, especially for the higher reading instrument, and absorbs the shorter wave lengths of light. All known suitably high index glass is so colored. (2) The glass is softer than that used in the standard Abbé and consequently loses its polish and the instrument its accuracy more easily than does the standard instrument. (A sharp boundary line is dependent in part upon a good optical prism surface.) (3) The liquids used in most high index work are solutions of sulphur and various iodides in methylene iodide. (1) Except when carefully and freshly prepared these liquids contain free iodine. This condition is virtually unavoidable when the solutions approach saturation for indices above 1.82. Such free iodine tends to combine with the lead of the glass and produces a thin iodide film which renders the boundary line indefinite. (4) The most serious limitation of all is not to be attributed to the high range of the instrument though it is experienced mainly in high index re-

fractometry. The free iodine referred to above results in coloration of the liquid and consequent light absorption. Such absorption is marked in any Abbé near the border of the light and dark field since the rays which define this border line are those of grazing incidence. Although the Abbé refractometer employs an extremely thin layer of liquid, the rays of grazing incidence pass longitudinally through the layer of liquid. Since liquids of higher index are most generally colored, this difficulty is commonly encountered in high index refractometry.*

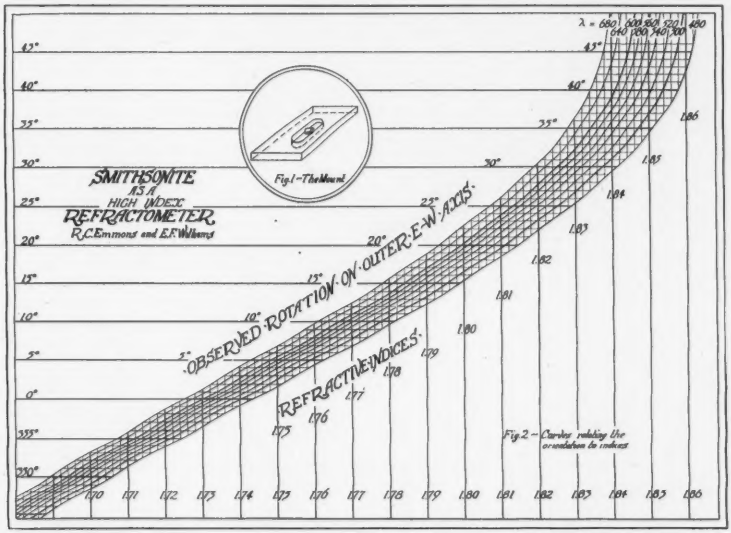

FIG. 1. Curves showing relationship of refractive index to orientation for smithsonite.

The method employed here exploits a crystal of high index and high birefringence, (2) smithsonite being chosen. An elongate hole was cut in a standard glass slide. To accomplish this a quarter inch brass tube, notched on the end, was mounted in a drill press and directed on the glass. Carborundum powder served as the abrasive. Two holes were cut close together and the opening was then shaped with a file. Over the opening a cover glass was cemented with water glass (sodium silicate). On the cover glass a small (2–3 mm.) cleavage fragment of smithsonite was cemented by one half, the other half being free of cement. The crystal should be so oriented that it rests on a cleavage face and the principal section is parallel with the length of the opening. The preparation is then complete (fig. 1).

The cavity may now be filled with

* The senior writer and his students have used a 1.84 Spencer Abbé refractometer since 1928 with care and find it reasonably satisfactory as high as 1.81. When new it functioned well over its entire range.

liquid and covered with a cover glass. Too large a cavity is inconvenient as it requires an excessive amount of liquid. The mount illustrated in figure 1 requires eight drops. The liquid is recovered when the examination is complete by removing the upper cover glass and tilting the slide against the dropper to guide the liquid back into the bottle. If the liquid contains sulphur it is desirable to wash the cavity with a small amount of carbon disulphide. Otherwise acetone may be used. A cloth should not be used to wipe out the inner surface lest it dislodge the crystal. Water, of course, cannot be used.

There are two methods of calibrating the mount, one empirical, the other theoretical. The theoretical method is preferred, checked by the empirical method. Once calibrated the mount is always ready for use. Place the mount on the universal stage equipped with a water cell (3) and cover with an upper hemisphere using liquid contacts. High index hemispheres should be used, 1.649 is satisfactory.

If the polariser of the microscope is not in the N-S position then rotate both nicols that it may be. Set the inner E-W and N-S axes at zero and clamp them permanently in this position. Insert the bertrand lens, set the outer E-W axis at 0° and center the illumination. Adjust the elevation of the mount if necessary, and *always use the same elevation*. Rotate on the inner vertical axis to make the principal section of the crystal parallel to the polariser—the crystal is then at extinction. (Or rotate on the outer E-W axis till the optic axis interference figure appears. A frosted glass below the polariser improves the quality of the figure if an arc lamp is the source of light. Center the interference figure by adjustment on the inner vertical and outer E-W axes. Remove the bertrand lens and analyser and rotate the crystal back on the outer E-W axis till the crystal and liquid agree approximately in index as indicated by the "Becke line" test. Introduce the analyser and bertrand lens again and adjust on the inner vertical axis to make the isogyre coincide with the N-S crosshair. This eliminates an error which may be introduced if the upper and lower surfaces of the cleavage fragment are not parallel to the plane of the slide.) Next change the illumination to monochromatic light, remove the frosted glass below the polariser and remove the analyser. Center the light accurately as viewed through the bertrand lens. *This is most important and is essential to accurate results.* It may be done easily and quickly and should be done for each change of illumination from white to monochromatic light.

The empirical method of calibration is as follows. Using two or three liquids such as α-iodonaphthalene (about 1.70), methylene iodide (about 1.74) and methylene iodide with sulphur and iodides (about 1.83) determine the positions of rotation on the outer E-W axis at which the crystal and liquids agree for as many wave lengths of light as curves are desired. The curves may then be drawn through these points. Intermediate

and end points may be readily determined with the help of Plates I and II of the paper referred to above (3).

The theoretical method of calibration is this. Determine the refractive indices of the crystal by grinding a suitable prism and following the minimum deviation procedure on a goniometer as outlined in standard texts (4). Then using Plates I and II of reference (3) determine a suitable number of points for the required curves.

The crystal used by us yielded the curves of Figure 2. The angle readings of the ordinate scale refer to the outer E-W axis of the universal stage. Follow the indicated horizontal line to the curve which indicates the wave length of light used, then down to the abscissa which gives the refractive index.

The curves of Figure 2 assume that the crystal is flat on a cleavage surface. In cementing the crystal to the proposed slide it is virtually impossible to cause it to be exactly flat. A correction is to be applied. To determine the correction make a mount of methylene iodide of which the index is known for a given wave length and temperature. Then determine the rotation on the outer E-W axis required to make the crystal and liquid agree in index. The difference between the theoretical and observed readings is the correction. In the mount we are using the correction is $+1.1°$ for the observed readings. There is a negligible departure for the corrections for steeper inclinations.

If the double variation procedure is employed (5) then instead of a microscope with universal stage and a refractometer side by side on one water circuit, two microscopes each with a universal stage are employed in the same manner on one water circuit. If calcite is used in place of smithsonite, indices as low as 1.486 may be read by this method, which figure includes most of our common minerals.

The cost of a universal stage is but little more than that of an Abbé refractometer, but the universal stage serves a larger number of uses. The accuracy of the procedure outlined here is less than that of the Abbé refractometer being $\pm.001$ as compared to $\pm.0002$. An outstanding advantage of this method of refractometry lies in the fact that it is more favorable to light transmissibility than is the Abbé refractometer when using colored liquids. This is particularly true near the ends of the visible spectrum. The convenience is slightly less than that of the Abbé.

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(2) Pauly, Anton, Uber eine einfache Methode zur Bestimmung der Brechungsexpenenten von Flussigkeiten: *Zeit. f. wiss. Mik.*, vol. 22, pp. 344–348, 1905. This paper deals with a re-related idea.
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(5) Emmons, R. C., *Am. Mineralogist*, vol. 14, p. 414, 1929.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 4, NO. 1, PP. 36–44, FIGS. 1–4 TABLES 1–3,
APRIL, 1934

A MINERALOGICAL STUDY OF LOESS NEAR ST. CHARLES, *MISSOURI*

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St. Louis University, St. Louis, Missouri

ABSTRACT

A mineralogical study of an exposure of buff loess overlying gray loess near St. Charles, Missouri, indicates that the buff loess was produced by the weathering and oxidation of the gray loess, and that the difference in color is due chiefly to the greater amount of iron oxide and iron rich beidellite in the buff than in the gray loess. A comparison of this loess deposit with the profile of weathering described by Leighton and MacClintock as developed on the till deposits of Illinois indicates that this exposure of loess is an example of a youthful profile of weathering developed on loess.

An exposure of buff loess overlying gray loess was found about three miles southeast of St. Charles, Missouri. This succession of buff loess overlying gray loess is considered by some geologists to be the result of two periods of deposition, the gray being the older and separated from the buff by a time interval or unconformity. Others consider the succession of buff loess overlying gray loess as one deposit of loess modified by weathering processes and, in many respects, this exposure of loess resembles the profile of weathering described by Leighton and MacClintock[1] as developed on the till deposits of Illinois. It has seemed probable that a detailed mineralogical study of this buff and gray loess would furnish the information necessary to determine if the buff and gray consists of two loesses of different ages or of one loess modified by weathering processes. The purpose of this paper is to present the results of a detailed mineralogical study made of the buff and the gray loess together with a conclusion as to the origin of the succession of buff loess overlying gray loess.

Acknowledgments. — The writer wishes to express gratitude and appreciation to Dr. V. T. Allen of St. Louis University for suggesting this problem, for his helpful suggestions in both the field and the laboratory, and for a critical reading of the manuscript; to Mr. W. D. Shipton of Washington University, St. Louis Missouri, for calling attention to the Garrett School loess; and to the Department of Geophysics of St. Louis University for the use of the equipment necessary to carry on this investigation.

DESCRIPTIONS OF LOESS EXPOSURES

The exposure of loess mentioned in the introduction was found on Highway 40 about one-half mile north of

[1] Leighton, M. M., and MacClintock, P., Weathered zones of the drift-sheets of Illinois: Jour. Geology, vol. 38, pp. 28–53, 1930.

the junction of Natural Bridge Road and Highway 40 where the highway cuts through a hill of loess that rises about 13 feet from the surface of the road (fig. 1). This loess shows the characteristic columnar structure, the columns extending from near the base of the hill to within four feet of the surface of the exposure where the texture of the loess becomes loose and crumbly. The contact between the buff and the gray loess is marked by a narrow band of iron oxide. Near the north end of this exposure, the succession of buff loess overlying gray loess is reversed, and, locally, gray loess rests on buff loess. The contact of this buff loess with the rest of the hill on the north end is almost vertical, but on the south end the contact makes an angle of 30° (see fig. 1). A complete vertical section of this exposure was taken for laboratory study from the place indicated in Figure 1.

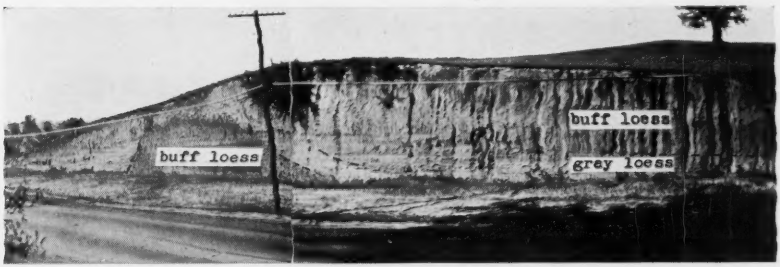


FIG. 1. Buff loess overlying gray loess on Highway 40. The position from which the vertical section was taken is to the right of labels, "buff loess" and "gray loess."

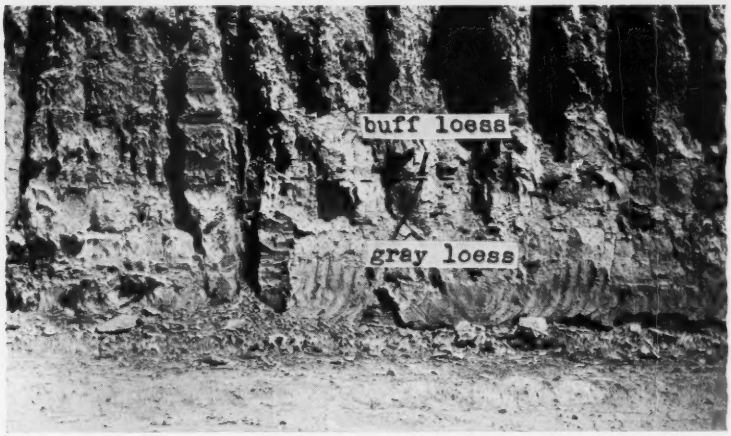


FIG. 2. Position from which the vertical section was taken marked by hammer.

A closer view of this position is shown in Figure 2. Samples were also taken of the loose material about 2 feet from the surface of the hill, and of the buff loess from the position in the hill where the buff underlies the gray.

Another exposure of buff loess overlying gray loess was found about 2¼ miles northeast of this hill and not far from Garrett School. This loess is called Garrett School loess to distinguish it from the loess on Highway 40. This Garrett School loess looks very much like the loess on Highway 40, except that it contains many tiny gastropod shells in both the buff and the gray loess. Tiny, irregular nodules of calcium carbonate are also found throughout the deposit. Samples for mineralogical study were taken of this Garrett School buff and gray loess.

GENERAL NATURE OF THE LOESS

The texture is uniformly fine-grained throughout. The bulk of the particles range in size from 0.01 mm. to 0.05 mm. in diameter. The compactness or cohesion of the particles usually varies with the distance from the surface of the exposure. The gray loess is more compact than the overlying buff loess, the texture becoming less compact toward the surface. A careful examination of the region of contact shows that the buff loess near the contact is not uniformly colored but contains irregular spots of gray loess. A preliminary microscopic study of the samples of the buff and gray loess shows that both are composed chiefly of angular to subangular grains of quartz, feldspar, and ferromagnesian minerals. Calcium carbonate is found to be abundant in the buff and in the gray loess of Garrett School, but in the loess of Highway 40, calcium carbonate is present in the gray and absent in the buff.

MINERALOGICAL STUDY

The distribution and nature of the minerals heavier than bromoform (2.9) is discussed under the heading "Heavy Minerals." The feldspars and quartz are considered under the heading "Light Minerals," together with a discussion of the nature, distribution, and origin of the chief clay mineral found in this loess.

Heavy Minerals

Samples of loess weighing 100 grams each were taken from the positions indicated in Table 1. Each sample was washed six or seven times in a miner's pan until most of the clay was removed. The residues were then dried and the heavy minerals separated by the use of bromoform (2.9). These heavy minerals were then

TABLE 1

Bottom of gray	Top of gray	Bottom of buff	Near top of buff	Loose top material	Buff under gray	Gray G. S.†	Buff G. S.†
0.20%	0.05%	0.10%	0.09%	0.05%	0.11%	0.07 %	0.20%

† G. S.—Garrett School.

weighed. Table 1 shows the percentage of heavy minerals in each sample stated in terms of the total weight.

The variations in the percentages of heavy minerals in the buff and the gray loess are too irregular to be of value in the determination of the limits of this deposit.

The results of a study of the distribution of the minerals identified in each of these samples is shown in Table 2.

The table shows a striking uniformity of composition in the different samples. The abundance of hornblende is noteworthy for it is usually one of the first minerals to be decomposed when subjected to the ordinary processes of weathering. These hornblende grains are usually prismatic and of a bright green color. Only a few of the grains show a brown staining along the cleavage or fracture planes. The augite grains are pale-green to colorless and of very irregular shapes. The grains of tourmaline are prismatic and show strong absorption—deep olive-green and very pale olive-green. There are smaller amounts of a tourmaline with an absorption formula of a deep brown color in one direction and pale brown in the other direction. The garnet is mostly colorless, and the grains have very irregular shapes, but there are a few grains of a decidedly pink color. The zircon occurs in pale-yellow euhedral crystals. Small irregular grains of a mineral with a yellow-green color were identified as epidote. Rutile occurs in reddish-brown euhedral grains.

Light Minerals

(*a*) *Feldspars and Quartz.*—Differences in the weathering of different parts of a sedimentary deposit are often shown by a variation in the percentage of quartz to feldspar grains. For the purpose of determining any such variation in different parts of loess, the number of quartz and feld-

TABLE 2

Minerals Sp. Gr. > 2.9 B Abundant C Very common D Common E Rare F Present Minerals Sp. Gr. < 2.9 A Present	Hornblende (green)	Hornblende (brown)	Augite	Garnet	Tourmaline	Zircon	Apatite	Rutile	Titanite	Epidote	Limonite	Magnetite	Biotite	Chlorite	Leucoxene	Feldspar	Quartz
Bottom of gray	B	D	D	D	C	D	F	F	F	D		C	A			A	A
Top of gray	B	C	E	D	D	D		F		D		D	A			A	A
Bottom of buff	C	E	D	D	C	D	F		F	D	B	D	A		A	A	A
Near top of buff	C	E	F	D	D	D	F			C	C	D		A	A	A	A
Loose top material	D	E	F	D	D	D	F	F	F	D	C	D		A	A	A	A
Buff under gray	C	F		D	D	D	F			E	D	D	A	A	A	A	A
Gray, Garrett School	C	D	D	D	D	D	F			D		D				A	A
Buff, Garrett School	C	F	D	D	D	D	F			D	D	D	A			A	A

spar grains in small samples of loess were counted until at least 100 grains were obtained from each of the positions indicated in Table 3. Table 3 shows the results of this count together with the relative proportions of feldspar and quartz in different parts of loess.

The percentages show a slightly greater proportion of quartz to feldspar in the buff than in the gray loess, but the differences are not great enough to be of any important significance.

TABLE 3

	Quartz	Orthoclase	Plagioclase	Microcline	Total	Per Cent Quartz	Per Cent Feldspar
Bottom of gray	95	56	4	1	156	60.9	39.1
Top of gray	68	35	2	...	105	64.8	35.2
Bottom of buff	81	38	3	2	124	65.3	34.7
Near top of buff	89	33	2	...	124	71.8	28.2
Loose top material	79	31	2	4	116	68.1	31.9
Buff under gray	89	33	3	4	129	69.0	31.0
Gray, Garrett School	75	35	2	4	116	64.7	35.3
Buff, Garrett School	71	49	3	2	125	56.8	43.2

(*b*) *Clay Mineral in Loess.*—A finely micaceous, pale-brown mineral, identified as beidellite is the chief clay mineral in this loess. Beidellite, according to the classification of Ross and Kerr,[2] belongs in the montmorillonite-beidellite group of clay minerals. As a result of a study of this montmorillonite-beidellite group of clay minerals, Larsen and Steiger[3] found that the nontronite and beidellite members of this group form an isomorphous series with no important gaps. A study of the optical properties of the members of this series as compared with the optical properties of beidellite in loess indicates that the beidellite in loess should have a place between the beidellite from Beidell, Colorado, and the beidellite from Spokane, Washington. The optical properties of each of these minerals are as follows:

The type beidellite, "leverrierite" gouge clay from Beidell, Saguache County, Colorado.

α $\beta\gamma$ $\gamma-\alpha$

1.494 1.536 .042 small 2V, negative

Beidellite in loess.

$\beta\gamma$

$1.566 \pm .005$ small 2V, negative.

An iron-rich beidellite, Spokane, Washington.

α $\beta\gamma$ $\gamma-\alpha$

1.523 1.572 .049 small 2V, negative.

Now all the beidellite analyzed by Larsen and Steiger[4] contain some iron, varying from 0.08 per cent to

[2] Ross, Clarence S., and Kerr, Paul F., The clay minerals and their identity: *Jour. Sedimentary Petrology*, vol. 1, no. 1, p. 57, 1931.

[3] Larsen, E. S., and Steiger, G., Dehydration and optical studies of alunogen, nontronite and griffithite: *Am. Jour. Sci.*, vol.15, pp. 1–19, 1928.

[4] *Op. cit.*, p. 14.

18.54 per cent. Ross and Kerr[5] state that iron may be substituted for alumina in beidellite and so form an essential part of the clay substance, and the analyses of Larsen and Steiger[6] show that as the content of Al_2O_3 increases the content of Fe_2O_3 decreases. The per cent of Fe_2O_3 in the beidellite in loess may be approximated from its position in the isomorphous series of beidellite and nontronite. The beidellite of Beidell, Colorado, has an iron content of 8.68 per cent. The beidellite of Spokane, Washington, has an iron content of 18.54 per cent. The estimated percentage of Fe_2O_3 in the beidellite in loess would thus be about 17 per cent.

The index of refraction of beidellite has been found to increase with depth in a mature profile of weathering,[7] a profile of weathering being a vertical section of the zone of weathering. A study of the index of refraction of beidellite in loess at different depths shows no such variation with depth (see Table 4). It would thus be concluded that the beidellite in this loess presents evidence of a youthful rather than a mature profile of weathering.

Beidellite is found in both the buff and the gray loess, although there appears to be a slightly greater concentration in the buff than in the gray. That the color of the buff loess may be partly due to this concentration of beidellite may be inferred from a study of the thin sections of loess for, there, the dark areas contain much beidellite, while the lighter areas contain little beidellite.

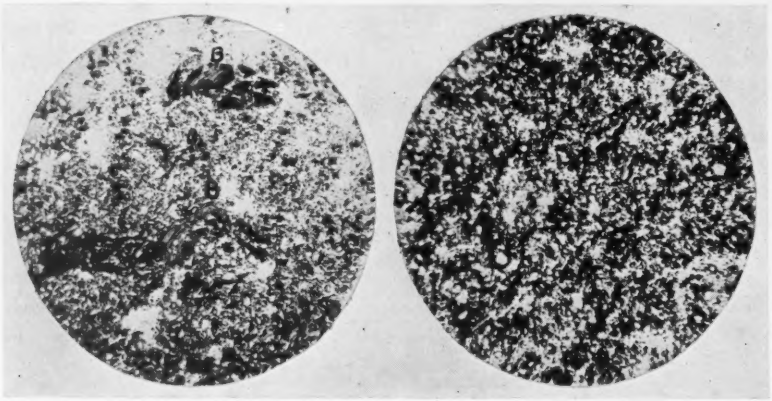
As to the origin of this mineral, beidellite, it is believed to be the product of the decomposition of feldspars or ferromagnesian minerals. V. T. Allen,[8] in a comparison of the underclays of Illinois coal with glacial till, shows microphotographs of beidellite being derived, in situ, both from feldspar and from epidote in glacial till. Microphotographs of thin sections of loess show no grains of feldspar or ferromagnesian minerals partially altered to beidellite. The beidellite occurs in a groundmass composed chiefly of quartz and feldspar grains (fig. 3*a* and 3*b*). The dark streaked areas in Figure 3*a* are aggregates of micaceous plates of beidellite cut perpendicular to the

[5] *Op. cit.*, p. 62.
[6] *Op. cit.*, p. 15.
[7] Allen, V. T., Petrographic and mineralogic study of the underclays of Illinois coal: *Am. Ceramic Soc., Jour.*, vol. 15, no. 10, p. 565, 1932.
[8] *Op. cit.*, p. 567.

TABLE 4. *Comparison of the Indices of Refraction at Different Depths*

	Depth from surface (ft.)	Index of refraction $\beta\gamma$
Loose top material	2	$1.566 \pm .005$
Buff loess	6	$1.566 \pm .005$ chiefly $1.557 \pm .005$ a few grains
Buff loess	10	$1.566 \pm .005$ chiefly $1.557 \pm .005$ a few grains
Gray loess	13	$1.566 \pm .005$

section. The other dark areas in the same section are chiefly plates of beidellite with the planes of cleavage parallel to the plane of the section. The unaltered nature of the feldspars and ferromagnesian minerals together with the absence of minerals partially altered to beidellite suggests that the beidellite in loess did not originate within the formation in which it is now found. Its occurrence in both the gray and the buff loess indicates that it was not brought from the surficial soil by circulating solutions, but rather that it was formed in a different environment and transported and deposited with the other minerals in the deposit.



a *b*

FIG. 3*a*.—Buff loess. Dark areas are beidellite (B). Small white areas are chiefly quartz and feldspar. Large white areas are holes in the section. 100 in. from bottom of hill. ×39.

FIG. 3*b*.—Gray loess. Dark areas are beidellite. Light areas are chiefly quartz, calcite, and feldspar. 3 in. from bottom of hill. ×39.

THE BUFF LOESS UNDER THE GRAY LOESS

Near the north end of the hill where the usual sequence of buff loess over gray loess is reversed and gray loess is found locally to rest on buff loess, the buff loess does not show the columnar structure characteristic of loess and the texture is less consolidated than that of the buff loess in the major part of the deposit. The loose texture and the lack of columnar structure might be compared with the nature of the loose material found in the upper four feet of the central part of the hill. The operation of surface conditions might then be thought to be an explanation of this deposit, but the form of the deposit does not conform to the general contour of the hill. To the north, the contact with the other loess is abrupt, and to the south, it is gradual. This is the reversal of the conditions that one would expect if the form of the deposit were the result of surface conditions. The loose texture suggests

that some underlying cause may have initiated a slight slumping, a slumping great enough to loosen the texture of the overlying material, but not great enough to have any effect on the topography of the hill. In fact it suggests a sort of embryo sink hole. The underlying formation is probably limestone, and it is very likely that the partial solution of this underlying rock has loosened the texture of the overlying loess. With increased porosity, there has been increased circulation of solutions so that the gray loess has been oxidized to buff loess. Certainly, at this locality, the buff loess is not a definite stratigraphic horizon for in some places it is below the gray and in other places it is above the gray.

COMPARISON WITH THE PROFILE OF WEATHERING

The oxidized and leached buff loess overlying unoxidized, calcareous loess closely resembles the profile of weathering described by Leighton and MacClintock[9] as developed on the till deposits of Illinois. On the Illinoian drift the profile is mature and consists of four horizons and an unweathered till below these that may be designated as horizon five. A diagram of a profile of weathering in loess, based on the mineralogical study of loess made in this paper, was made and compared with the profile of weathering on Illinoian till (Figs. 4*a* and 4*b*). The loess profile consists of

[9] *Op. cit.*, pp. 28–53.

FIG. 4. COMPARISON OF AVERAGE MATURE PROFILE OF WEATHERING ON ILLINOIAN TILL WITH THE PROFILE OF WEATHERING ON LOESS
(Both diagrams drawn to the same scale)

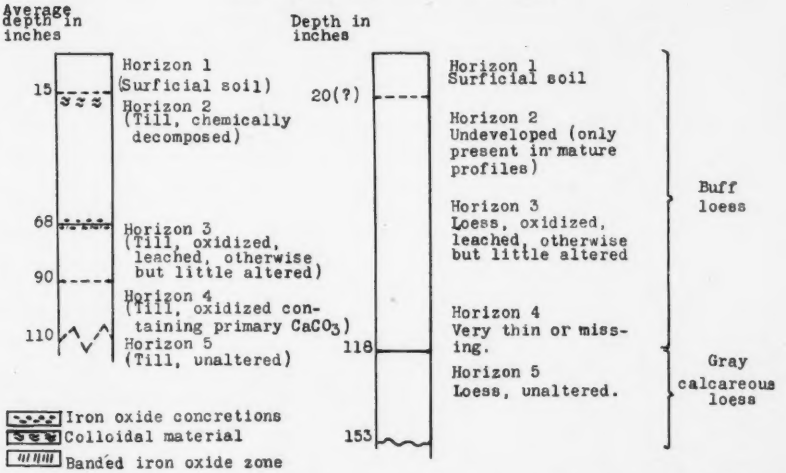


FIG. 4*a*.—Diagram of an average of mature profiles developed on Illinoian till.
(After M. M. Leighton and Paul MacClintock, *Op. cit.*, p. 46.)

FIG. 4*b*.—Diagram of profile of weathering on loess.

only three horizons as compared with the five horizons developed on Illinoian till. In loess the band of iron oxide is at the bottom of a leached and oxidized horizon and in till the band of iron oxide is at the bottom of a chemically decomposed horizon. A chemically decomposed zone has not been developed in the buff loess, for the mineralogical study of loess shows that the feldspars and the ferromagnesian minerals in the upper part of the deposit are as fresh as those lower down. The less obviously differentiated horizons of the loess profile of weathering with the lack of decomposition of the silicate minerals is evidence that the loess has developed a youthful profile of weathering in contrast to the mature profile of weathering, typical of the Illinoian drift.

CONCLUSION

The nature and distribution of the minerals in the buff and the gray loess presents no evidence that these two parts of loess are stratigraphically not of the same age. A study of the region of contact between the buff and the gray loess shows no evidence of a time interval between these two types of loess, such as an old soil, remains of plant or animal life, or an old erosional surface. The lack of calcium carbonate in the buff loess on Highway 40, as compared with the underlying calcareous gray loess presents no evidence of a stratigraphic unit, for in the Garrett School loess, both buff and gray contain abundant calcium carbonate. The difference in color between the two loesses is due chiefly to the greater amount of iron oxide and iron-rich beidellite in the buff than in the gray loess.

The resemblance of this succession of buff loess overlying gray loess to the profile of weathering, described by Leighton and MacClintock, is most striking and a comparison of this loess deposit with the profile of weathering, together with a consideration of the results of the mineralogical study of the buff and the gray loess, leads to the conclusion that the succession of buff loess overlying gray loess was not the result of the deposition of two loesses separated by a time interval or unconformity, but rather that it is one loess modified by weathering processes. The buff loess was produced in all places by the weathering and oxidation of the gray loess, but weathering, in no part of these deposits, has reached the stage where silicate minerals were affected, or proceeded to such an extent that the index of refraction of the clay mineral has increased. The succession of buff loess overlying gray loess is an example of a youthful profile of weathering developed on loess.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 4, NO. 1, PP. 45–46,
APRIL, 1934

THE PETROGRAPHIC STUDY OF CLAY MINERALS—A LABORATORY NOTE[1]

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ABSTRACT

The individual clay mineral particles that compose clayey sediments are usually too small to permit their optical properties to be determined. A technique is described for obtaining aggregates of clay mineral particles in which all the individual particles have about the same optical orientation so that the optical constants of the clay mineral can be measured easily and accurately. The problem presented by fine calcite, which masks the optical constants of the clay mineral and of which the removal is difficult without altering the clay mineral, is met by an improved method for eliminating fine calcite from calcareous sediments.

As a part of the research program of the Illinois State Geological Survey, a detailed petrographic study has been made of certain of the fine grained sediments occurring in Illinois. Optical, X-ray, chemical, and dehydration data have been used to obtain determinations of the clay mineral constituents of these rocks. The preparation of the clay minerals for the study was largely a matter of separation and purification by sedimentation methods. The determination of the optical constants presented difficulties that were overcome largely by the following technique, which is presented in the hope that it may be of value to other workers in this field.

The clay or shale is first disaggregated in distilled water. In our laboratory this is done in an end-over-end shaker with a speed of about 40 r.p.m. After thorough disaggregation the material is placed in a large glass vessel with sufficient additional distilled water to produce a fairly thin suspension, and is allowed to stand until all the nonclay minerals appear to have settled to the bottom. Portions of the suspension may be withdrawn from time to time, dried, and checked microscopically for the presence of nonclay mineral grains. A glass slide of the type used in making thin sections is then suspended by means of a wire sling in a horizontal position in the upper part of the suspension, and is allowed to remain there until some of the clay mineral material has settled on the slide. As most species of clay minerals are flat flake-like particles, they tend to accumulate with one of their flat surfaces parallel to the surface of the slide. After a considerable quantity has accumulated, the slide is lifted out of the suspension and dried. If possible, the layer on the slide after drying should be at least as thick as an ordinary thin section (0.03 mm.) although lésser thicknesses can be

[1] Published with the permission of the Chief, Illinois State Geological Survey, Urbana, Illinois.

used. Slices of the dried aggregate about 0.03 mm. thick are then shaved off by using a razor blade, and are mounted in index of refraction liquids for the measurement of optical constants. The coated glass slides form a convenient way of storing the purified material for future reference.

Individual particles of the aggregate thus obtained are too small to permit optical measurements to be made on them, but these measurements can be made on the aggregates themselves with ease and accuracy. Aggregates can be found occasionally in which the constituent particles possess sufficient uniformity of orientation to yield interference figures from which the optical sign and a value for 2V can be obtained. In most clay minerals a bisectrix is about perpendicular to the basal cleavage plane and the aggregates are essentially superimposed basal planes with their vertical axis about parallel. Aggregates that yield interference figures are those in which the horizontal crystallographic directions of the component particles also happen to be about parallel. Usually those aggregates that are most likely to yield interference figures are composed of comparatively few individual particles.

It has been found by experience that most satisfactory results are obtained when the component particles have an average diameter of about one micron, and this can usually be attained by allowing the disaggregated material to stand some time before inserting the suspended glass slide.

A deflocculating agent must be used occasionally when it is otherwise impossible to obtain a satisfactory suspension. Because of base-exchange capacity and adsorptive ability of certain clay minerals with attendant variations in optical values, strong acids and bases should be avoided. Organic deflocculants appear to be least objectionable. The writer has found, however, that repeated wetting with distilled water and drying, followed by prolonged agitation in a shaker, will usually yield a suspension sufficient to obtain a coated glass slide without using a deflocculating agent.

The chief difficulty encountered in using this technique has been the presence of fine quartz in the aggregate of clay mineral particles. Some clays and shales studied contain quartz grains with a diameter of one micron or less which so far have defied physical separation from the clay mineral. It is very difficult and at times impossible to obtain accurate optical data if appreciable quartz is present in the aggregate.

In certain calcareous clays and tills, calcite occurs in particles small enough to hinder its physical separation from the clay mineral. Thus aggregates composed of mixtures of these two minerals result. In these, calcite effectively masks the optical values of the clay mineral. This difficulty has been overcome by passing a stream of carbon dioxide gas through the suspension and dissolving the calcite as the bicarbonate. This action is sufficiently mild so that the clay minerals are unaffected.

X-ray analyses have been made of identical samples treated and untreated with carbon dioxide, and the only difference observed in them was the absence or presence of lines characteristic of calcite. After the calcite is removed, the clay mineral aggregate can be obtained on the glass slide and their optical values determined as described.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 4, NO. 1, P. 47, APRIL, 1934

FURTHER EVIDENCE FOR SECONDARY OOLITES

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Several years ago the writer described a clastic deposit in central Missouri that is oolitic.[1] This deposit contains quartz and limestone grains and oolites of about the same size. The relationship of the grains shows that all had been derived from some nearby source.

The oolitic rock, the Sylamore sandstone (Lower Mississippian) of central Missouri, is divided into two members on a basis of lithology.[2] The lower member is a coarse-grained, ripple marked, cross-bedded sandstone about 11 feet thick. The upper member is a thin-bedded, bluish-green sandy shale about one foot thick. The oolites are found only in the lower member.

The writer advanced the following facts as the main evidence for the secondary character of the oolites:

(1) The clastic materials composing the formation are well sorted but are heterogeneous in composition.

(2) Some of the limestone grains contain oolites. The limestone grains are rounded and the oolites in the grains are truncated by the rounding.

(3) Hemispherical depressions in some of the limestone grains show evidence of having contained oolites.

The theory that most of the oolites studied from the Sylamore sandstone are derived from a pre-existing formation has been substantiated by additional evidence obtained since the publication of the above paper.

Research carried on in the paleontological laboratories of the University of Missouri shows the presence of worn transported conodont teeth in the oolitic beds of the lower Sylamore. Professors Branson and Mehl[3]

[1] Swartzlow, C. R., Oolitic rock of secondary origin, *Pan.-Am. Geologist*, vol. 53, pp. 197–200, 1930.

[2] A reference to the above paper in the second edition of the *Treatise on Sedimentation* erroneously locates this Sylamore deposit in Arkansas rather than placing it in Missouri.

[3] Personal communication.

state that the worn teeth represent a large number of species, and although badly worn, can be compared with earlier and later conodonts.

The conodonts found in the horizontal Sylamore directly above the cross-bedded oolitic members are not worn and are typical Sylamore species as they have been found over central Missouri. While Branson and Mehl are not ready to state that the worn teeth of the lower Sylamore are materially older than the typical upper Sylamore forms of this region, they do state that they are different.

The presence of worn, transported conodonts, the individuals of which are approximately the same size or smaller than the oolites is further evidence that the formation from which they were derived was close at hand and burial was rapid. Transportation over considerable distances or prolonged rolling back and forth over the beach sands would undoubtedly have destroyed the conodonts as well as the oolites and limestone grains associated with them.

BERRY, J. ALLAN, *The Volcanic Deposits of the Scinde Island, with special reference to the pumice bodies called chalazoidites.* Transactions New Zealand Institute, Vol. 59, 1928, pp. 571–608.

The volcanic deposits of Scinde Island, situated on the east coast of the north island of New Zealand, are described and referred to Mid-Pliocene, Pleistocene and Recent origin. The major portion of the article is devoted to consideration of ellipsoidal shaped bodies embedded in tuffs and ranging in diameter from about that of a pin head to about one-half inch. These bodies have a light-gray color in which are small dark rectangular patches. They seem to be perfectly homogeneous but staining has demonstrated that the structure is concentric and that the outermost layer usually is the most dense. The composing materials are mainly particles of colorless glass. Minor constituents are feldspar, quartz, and rarer substances. For these bodies the name of chalazoidites (Greek chalazoidos, resembling hail, and lithos, stone) is proposed. They represent the volcanic bodies which in other literature have sometimes been designated pisolites. With respect to origin, it is considered, (1) whether the chalazoidites were formed in the crater of the volcano from which the volcanic matter was expelled; (2) whether they formed in the volcanic ash deposits in which they are now embedded; and (3) whether they formed in the air after expulsion from the volcano and before deposition, something in the same way as hail is formed. The last explanation is adopted as the most plausible. A review of the literature dealing with similar structures concludes the article.

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STETSON, HENRY C., *Scientific Results of the "Nautilus" Expedition, 1931, The Bottom Deposits.* Papers in Physical Oceanography and Meteorology, Massachusetts Institute of Technology and Woods Hole Oceanographic Institution, Vol. 2, No. 3, Pt. 5, pp. 17–37, 1933.

This paper presents results of studies of eight bottom cores collected 80 to 100 miles northwest of Spitzbergen over an extent of about 270 miles by the Wilkins-Ellsworth Expedition of 1931. The cores range in length from 34–42 cm. (13.6–17.6 inches).

The cores were studied as to sizing and sorting, type and abundance of organic remains, calcium carbonate content, and the mineralogy of the sand portion. Stratification was clearly noted in only one core at the time the samples were first studied, but a core left in the tube showed, eighteen months after it had been taken, rhythmic laminae of remarkable clearness. The author suggests that the apparent development of stratification might be due to diffusion banding or rhythmic segregation of iron salts, or that "a real rhythm in sedimentation" may be represented. The origin of the sediments is discussed at some length.

The author's general conclusions and results are as follows:

1. The samples in the main are composed of a chocolate-brown clay which seems to be uniformly distributed over the area covered. Sorting is moderately well done.

2. The material is entirely terrigenous in origin and there is no trace of any of the pelagic oozes.

3. In general, the percentage of sand tends to increase downwards, as is reflected by increase in median diameters. There are no definite trends in the other grade fractions.

4. The foraminifera are all normal, Arctic, bottom-living forms of the present day. There is nothing in their distribution suggestive of past geologic changes.

5. The $CaCO_3$ content is directly de-

pendent on the relative abundance of calcareous foraminifera.

6. The organic content is comparable to other marine sediments from similar environments.

7. In general, the minerals are fresh and angular, although minor amounts of decomposition are shown by some of the ferro-magnesian group, and slight kaolinization has taken place in some of the feldspars. Hornblende, augite, olivine and garnet are the most abundant heavy minerals. Tourmaline, zoisite, titanite, zircon, biotite, muscovite, staurolite, epidote, andalusite, hypersthene and calcite are present in small amounts.

8. Stratification, suggestive of varving, is present in a few cases. It showed very clearly in a portion of core which was accidentally left in the container for a long time.

9. The statistical constants indicate a closer relationship with shallow-water, near-shore clays of fluviatile origin, than with true deepwater clays.

10. Sea-ice is suggested as an important transporting agent, the clay being washed out upon the fast-ice during the spring freshets of the rivers of the Siberian coast.

11. As a clay in deep water must accumulate very slowly, the evidence seems to point to the existence of stable conditions over a long period of time in the Arctic regions.

Data of the nature that is found in this paper are an important contribution to our knowledge of the bottom sediments of ocean basins.

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University of Wisconsin

BOSWELL, P. G. H., *On the Mineralogy of Sedimentary Rocks*. London: Thomas Murby and Co., 1933, 393 pp. (D. Van Nostrand Co., New York, $10.00).

The first one-third (125 pages) of this typical English book contains a number of well written but general discussions of important topics concerning sedimentary rocks. The balance of the book is devoted to a bibliography with abstracts of over one thousand articles dealing with the mineral constituents of sediments.

The eleven chapters of the first part of the book are listed here to give an idea of the nature of the subjects summarized. These chapters or essays are really reviews showing the progress of study and the type of data accumulated, but include some comments and suggestions by the author. Following the introductory chapter, which includes a list of detrital and authigenic constituents of sedimentary rocks, the topics discussed are: History of Investigation; The Individuality of Sediments; The Stability of Detrital Minerals; Minerals as Clues to the Source of Sediments; Correlation by Means of Minerals; Shore Sands and Dune Sands; Deep-Sea Sediments; Authigenic Minerals; The Mineral Composition of Clays; Detrital Minerals and the Origin of Metamorphic Rocks. Students of sedimentation will find this material excellent as a starting point for more extended investigations.

The chapters on the Individuality of Sediments, Minerals as Clues to the Source of Sediments, and Correlation by Means of Minerals convince the reader that the very large amount of petrographic work on the sediments of Great Britain has yielded valuable aids to the correlation of formations and the solution of problems of paleogeography. It seems reasonable to believe that such success has been favored by the small size of the areas involved and the nearness of most of the source rock. These methods of correlation are less convincing when applied to North American formations. The vastness of the North American geologic provinces, especially of the pre-Cenozoic rocks, the liberal reworking of older sediments and the general lack of petrographic knowledge of the sediments as well as igneous rocks prevent a fair application of the interpretations used by the British. We are about twenty years behind in this work but it is hoped that our belated interest will be greatly

accelerated to overcome the handicaps of time and great expanse of geologic formations.

The discussion of the Stability of Detrital Minerals is concise but for its purpose is the best that the reviewer has read. The information already in the literature is marshalled to emphasize the importance of giving consideration to the physical and chemical characters of minerals in determining source and origin and in the interpretation of history. The author backs Thoulet in his plea for the further study of the "pathology" of minerals; Harker's idea of greater stability of stress as compared to anti-stress minerals is given a prominent place in explaining the presence or absence of minerals in sediments.

The chapters on Authigenic Minerals and on Clays are excellent reviews of the subjects. Over forty authigenic minerals are listed (on page 7) and naturally considerable attention is given to the feldspar group. The evidence is strong for cold water formation of most authigenic feldspars (and for many other minerals) and it seems that the soda-potash types are most common. In the study of clay minerals it is apparent that the American investigators have made the most notable advances in recent years. It is apparent that this field of study can be greatly extended.

A very useful part of the bibliography is found in the indexes. The abstract material is cross-indexed in six separate arrangements. In addition to the general index are the groupings according to stratigraphic horizons, localities, minerals, figured minerals, and technique.

The book will no doubt fill a need of the workers in sedimentary petrography who do not have available a good library or bibliography. There are several institutions in North America that have a larger bibliography with abstracts than the one included in this volume. A possible exception to this statement may be made concerning some of the publications of limited circulation in the European literature. It is almost impossible for any one person or group to find *all* material on a subject and for that reason minor omissions can be overlooked.

It is regrettable that the material was not published in a less expensive form, as the price of ten dollars charged in the United States is beyond the privilege of most teachers and students.

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